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The resilience of combinatorial structure at the word level: morphology in self-styled gesture systems

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Abstract

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. The purpose of these studies is to determine whether deaf children who were not exposed to an accessible model of a conventional language would nevertheless incorporate word-level combinatorial structure into their self styled communication systems. In previous work, we demonstrated that, despite their lack of conventional linguistic input, deaf children in these circumstances developed spontaneous gesture systems that were structured at the level of the sentence, with regularities identifiable *across* gestures in a sentence, akin to syntactic structure. The present study was undertaken to determine whether these gesture systems were structured at a second level, the level of the word or gesture – that is, were there regularities *within* a gesture, akin to morphological structure? Further, if intra-gesture regularities were found, how wide was the range of variability in their expression? Finally, from where did these intra-gesture regularities come? Specifically, were they derived from the gestures the hearing mothers produced in their attempt to interact with their deaf children?

We found that all of the deaf children produced gestures that could be characterized by paradigms of handshape and motion combinations that formed a comprehensive matrix for virtually all of the spontaneous gestures for each child. Moreover, the morphological systems that the children developed, although similar in many respects, were sufficiently different to suggest that the children had introduced relatively arbitrary distinctions into their systems. These differences could not be traced to the spontaneous gestures their hearing mothers produced, but seemed to be shaped by the early gestures that the children themselves created.

These findings suggest that combinatorial structure at more than one level is so fundamental to human language that it can be reinvented by children who do not

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have access to a culturally shared linguistic system. Apparently, combinatorial structure of this sort is not maintained as a universal property of language solely by historical tradition, but also by its centrality to the structure and function of language.

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1. Introduction

Human language is both discrete and open. It is discrete in the sense that it contains elementary units, each associated with a particular meaning. It is open in the sense that messages are built using these familiar units, put together by familiar patterns, but yielding a composite total that may not have occurred before (Hockett, 1977). These properties of language are so fundamental that they are assumed, rather than highlighted, in all accounts of human language. They achieve salience primarily when contrasted with the properties of communication systems of other animals which, by and large, are holistic (i.e., designed to convey whole situations rather than to single out parts to be commented on; Bickerton, 1990). For example, bird calls, which consist of one or more short notes, convey global messages associated with the immediate environment (such as danger, feeding, nesting, flocking and so on) and are not combined with one another to create more complex messages (Thorpe, 1961). Slightly more complex, bird songs are combinatorial in the sense that they are composed of patterns of notes, but bird songs cannot be segmented into independently meaningful parts (Marler, 1960).

Those animal communication systems that do contain discrete elements, each associated with a distinct and specific meaning, do not permit novel combination of those elements; that is, they are not open. For example, vervet monkeys give different alarm calls to three different kinds of predators: pythons, martial eagles, and leopards (Seyfarth, Cheney, & Marler, 1980). The calls themselves (rather than any other behavioral or environmental feature) seem to refer to the predators and, in this sense, are comparable to words in human language. These monkey calls are different from words, however, in that they cannot be modified; that is, they cannot be combined with other elements to communicate, for example, that a python is *not* present. Finally, those animal communication systems that appear to be open do not achieve their productivity by combinations of discrete elements. For example, bee dancing can be considered an open system since a worker may report a location which has never been reported before. However, the mechanisms that render bee dancing productive involve analog and continuous mapping rather than the discrete categories characteristic of human language (von Frisch, 1966).

Human languages are distinct from all 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 several different levels. For example, 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.

Given the universality of structure both within the word and across words, and the fact that such combinatorial structure provides language with much of its flexibility, one might expect structure of this type to appear early in the communication systems of language-learning children. In fact, children begin the language-learning process in a single-word period during which they learn the words of their language as unanalyzed wholes or "amalgams" (MacWhinney, 1978). They then proceed in two directions.

One path that the child follows is to learn that words can be systematically combined to form meaningful sentences. For example, following a simple agent–object ordering rule, the English-learning child combines the word "mommy" (representing the agent) with the word "sock" (representing the object) to request mother to put the child's sock on (Bloom, 1970).

The other path the child follows is to learn that the word itself can be composed of parts (morphemes), each of which is meaningful. It is often difficult to know when a child has taken this step since the child may produce a word composed of parts without being aware that the word is, in fact, decomposable. It is primarily when the child begins to produce novel words formed from the combination of known parts that we can be sure that the child has grasped word-level structure. For example, initially a child might use the word "unbuckle" appropriately but not be aware that the word is composed of two parts, "un" and "buckle." Later, however, the child learns that "un" is a separable piece of the word associated with a particular meaning (i.e., to undo the result of an action), an insight reflected in the child's overgeneralized uses of "un" in novel words (e.g., "unbury" = to dig up a body, used in telling a ghost story; Bowerman, 1982). At this point, the child has gained productive control over the parts of words, knowing the parts themselves and how they combine to form words, and thus has structure at the level of the word.

All children, at a relatively young age, develop language systems with combinatorial structure at both word and sentence levels. They do so, in large part, because they are exposed to language models which have such structure. But is exposure to such a model necessary in order for children to incorporate combinatorial structure at word and sentence levels into their communication systems?

This question is difficult to explore simply because most children are surrounded by language-using adults who routinely provide them with models of combinatorial structure at both word and sentence levels. There are, however, children who are unable to make use of the conventional language model that surrounds them: deaf children whose hearing losses prevent them from taking advantage of the spoken language model around them, and whose hearing parents have chosen not to expose them to a conventional manual language such as American Sign Language (ASL) or to a manual code of a spoken language such as Signed English. In previous work, we have shown that deaf children of this sort, despite their lack of a usable conventional language model, develop gesture systems that have many of the properties of language, particularly when compared to the linguistic systems developed by comparably aged children exposed to language models (Goldin-Meadow & Mylander, 1990a).

We have studied the gesture systems of 10 deaf children of hearing parents from Philadelphia and Chicago, and found compelling structural similarities between their gestural systems and conventional languages at both the lexical level (Butcher, Mylander, & Goldin-Meadow, 1991; Feldman, Goldin-Meadow & Gleitman, 1978; Goldin-Meadow, Butcher, Mylander, & Dodge, 1994) and the syntactic level (Goldin-Meadow, 1982, 1987; Goldin-Meadow & Feldman, 1977; Goldin-Meadow & Mylander, 1984). In other words, the deaf children used their gestures in many of the ways that words are used in conventional languages, including combining those gestures into sentences characterized by both ordering and deletion regularities. Thus, combinatorial structure at the sentence level can be incorporated into a communication system developed without a model of a conventional language (i.e., without a model shared within a community of users and passed down from generation to generation). This finding suggests that sentence-level structure is not maintained as a universal property of language solely by historical tradition but also by its centrality to the structure and function of language.[1]

The purpose of this study is to determine whether the gesture systems developed by the deaf children in our studies, in addition to having structure at the level of the sentence (akin to syntactic structure), also have structure

[1] It is important to note that we are not claiming that children who learn language from a historically transmitted model do not have *productive* control over their language. Sentence-level structure is an important component of all natural languages and is learned effortlessly – and productively – by the vast majority of children. Nevertheless, it is possible that a child inventing language without a model might not, on his or her own, arrive at this type of structure. The question we ask in this study is whether children can *introduce* structure at the level of the word as well as the sentence even if provided with no explicit model for such structure.

at the level of the word or gesture (akin to morphological structure); that is, to determine whether the deaf children's gesture systems, like all natural human languages (but like no animal communication systems), have combinatorial structure at both word and sentence levels.

In our previous work, we have explored within-gesture structure in one of the deaf children in our sample and found that this child's gestures were, in fact, composed of parts and thus appeared to be characterized by morphological structure (Goldin-Meadow & Mylander, 1990b). However, in the face of extreme variation from the conditions under which language-learning typically proceeds, morphological structure tends to be less resilient than at least certain types of syntactic structure. For example, individuals learning a language late in life, as a group, have no difficulty mastering word order in that language but do far less well in mastering the morphological aspects of the language. This poor performance reflects the fact that some individuals do well on morphology while others do quite poorly (unlike word order on which all individuals do well; Newport, 1990). The contrast between learning morphology and learning word order has been found in individuals learning a first language beyond puberty (Curtiss, 1977; Newport, 1990), as well as in individuals learning a second language beyond puberty (Johnson & Newport, 1989, 1991). Thus, there is more variability in performance across individuals learning morphology late in life than across individuals learning word order late in life. Learning morphology appears to be more sensitive to circumstances of acquisition than learning word order.

Given this apparent fragility, we might expect to find that the unusual circumstances of acquisition in which the deaf children in our studies find themselves would have more dramatic effects on the development of morphology than on the development of word order. If so, we might find variability in the gesture systems of the deaf children in terms of patterns within gestures (i.e., morphological structure), even though we found little variability in terms of ordering patterns across gestures (i.e., syntactic structure). We explore this issue in Study 1 in which we examine structure at the word level in the gestures of four deaf children (the child from our Philadelphia sample described in Goldin-Meadow & Mylander, 1990b, and the three deaf children from our Chicago sample).

STUDY 1: MORPHOLOGICAL STRUCTURE IN THE DEAF CHILD'S GESTURES

The self styled gesture systems of the deaf children in our sample were indexical and iconic systems of representation. The "lexicon" of the gesture systems contained both pointing gestures and characterizing gestures. Pointing gestures were used to indicate objects, people, places, and the like in the surroundings. Characterizing gestures were stylized pantomimes whose iconic forms varied with the intended meaning of each gesture (e.g., a fist pounded in the air to indicate that someone was hammering). As described above, the children combined these gestures into strings that functioned in a number of respects like the sentences of early child language and were consequently labeled "gesture sentences". As an example, one child produced a pointing gesture at a bubble jar (representing the argument playing the patient role) followed by the characterizing gesture TWIST (representing the act predicate) to request that the experimenter twist open the bubble jar (Goldin-Meadow & Mylander, 1984).

In order to explore word-like structure in the deaf child's gesture system, we need first to identify what a word is. This is far from a trivial question even when dealing with conventional languages (cf. Spencer, 1991). For example, Matthews (1974, p. 31) distinguishes three notions of the word, each on a different linguistic level: (1) the word in phonology or orthography (the phonological word); (2) the word in grammar (the syntactic word); and (3) the word in the lexicon (the lexeme). The difficulty lies in the fact that each of these notions carves out a set of entities that may differ, however slightly, from one another. Thus, the phonological word, for example, is not in all cases co-extensive with the syntactic word. We chose to use a syntactic definition of the word in our study for two reasons. First, we have not yet explored what a phonological word might be in the deaf child's gestures, nor is it feasible to talk of a separable lexicon that is independent of the gestures we observe. Second, and more importantly, our goal was to determine whether there was structure in the deaf child's gestures not only within the sentence, but also within the units that comprised the sentence. It therefore seemed appropriate to isolate as "words" the units in the deaf child's gestures upon which the syntactic regularities of deletion and ordering operated. We consequently chose the characterizing gesture as the focus of our search for word-like structure in the deaf child's gesture system.

Note that, if we do find structure within the characterizing gesture, our rationale for selecting the gesture as our unit of analysis ensures only that we have identified two levels of structure in the deaf child's gestures – structure across gestures and structure within the gesture. It does *not* ensure that the second level of structure is, in fact, morphological structure. We are comfortable calling this structure "morphological" in large part because of its parallels to sign language. The gesture used by the deaf children in our study is akin to the sign in conventional sign languages. The sign is the unit upon which regularities are described in syntactic analyses of ASL (e.g., Liddell, 1980; Lillo-Martin, 1991), and the sign is the unit whose component parts are described in morphological analyses of ASL (e.g., Klima & Bellugi, 1979; Wilbur, 1987; Supalla, 1982). Indeed, our search for morphological structure in the deaf children's gesture systems was guided by descriptions of morphology in ASL; we therefore begin by reviewing the findings of this literature that are relevant to our analyses.

1.1. Structure at the level of the sign in American Sign Language

1.1.1. ASL morphology

Signs in ASL were originally thought to be built on an analog use of movement and space in which movement is mapped in a continuous rather than a discrete fashion Cohen, Namir, & Schlesinger, 1977; DeMatteo, 1977). In other words, signs were thought not to be divisible into component parts, but rather were considered unanalyzable lexical items that mapped, as wholes, onto events in the world. However, more recent research has shown that the signs of ASL (and other sign languages) 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 highly mimetic in form (as contrasted with the "frozen" signs of ASL that are listed in ASL dictionaries as single-morpheme stems). Mimetic signs in ASL have been shown to be constructed from discrete sets of morphemes and to include in the stem, at a minimum, a motion morpheme combined with a handshape morpheme (McDonald, 1982; Newport, 1981; Schick, 1987, 1990; Supalla, 1982). Morphemes in ASL (as in spoken languages) 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, little finger 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). Along with the motion and handshape morphemes, the stem may also contain a variety of other morphemes (Supalla, 1982). For example, if the moving object has a special manner of motion along its path (e.g., bouncing or rolling), a manner morpheme is added to the stem. If the moving object has a special orientation or direction of motion (e.g., moving backwards or upwards), an orientation morpheme is added to the stem.

In addition to these aspects of stem construction, Supalla and Newport (1978) have described another facet of word formation in ASL – the process of deriving nouns and verbs. Many of the verbs in ASL are related in both meaning and form to a particular noun. For example, the verb GO-BY-AIRPLANE (i.e., FLY) expresses the activity performed with the object AIRPLANE, and the forms for both the activity and the object have characteristics in common (e.g., the index, little finger, and thumb handshape). Supalla and Newport posit a shared underlying representation for related nouns and verbs, along with a pair of manner rules which, when applied to the underlying form, serve to distinguish noun from verb. In the above example, FLY and AIRPLANE resemble one another at an underlying level. When continuous manner is added to the underlying form, the verb FLY is produced; when restrained movement is added to the same form, the noun AIRPLANE is produced.

Regardless of whether a sign is a frozen lexical item or constructed by the productive processes described above, there are yet further modifications that it can undergo (Wilbur, 1987). Nouns can undergo a few limited modifications, such as the pural; verbs, however, are eligible for a variety of modifications, such as aspect and distribution (Fischer, 1973; Fischer & Gough, 1978; Klima & Bellugi, 1979). The functions of inflectional processes in ASL greatly exceed those in English yet, like spoken language morphology, these processes apply in an ordered and recursive fashion (Wilbur, 1987).

1.1.2. Acquisition of ASL morphology

The earliest signs produced by deaf children acquiring ASL from their deaf parents (second-generation deaf)[2] are lexical items that are uninflected citation forms (Ellenberger & Steyaert, 1978; Fischer, 1973; Hoffmeister, 1978; Meier, 1981; Newport, 1981; Newport & Ashbrook, 1977). These signs are either frozen signs (stems with no internal stem morphology) or signs which, although morphologically complex forms for the adult, are unanalyzed amalgams for the child (Newport, 1981). At around age 2;6, deaf children learning ASL begin to acquire discrete morphemes one at a time, and (as in the hearing child's acquisition of morphologically complex spoken languages) morpheme acquisition continues in the deaf child until at least age 6;0 (Kantor, 1980; Schick, 1986; Supalla, 1982).

However, 90% of deaf children are born to hearing parents and thus are unlikely to be exposed to ASL from birth (Hoffmeister & Wilbur, 1980). In fact, many of these "first-generation" deaf children are not exposed to ASL for the first time until adolescence or adulthood (ages 12–21). Unlike the second-generation deaf who learn ASL from birth and show complete mastery of ASL morphology when tested as adults, first-generation deaf have been found to have only partial control of ASL morphology as

[2] The term "second-generation deaf" refers to all deaf children born to deaf parents; thus, the term includes those relatively rare deaf children whose parents and grandparents (great-grandparents, etc.) are also deaf; that is, the term includes children who are third-generation (fourth-generation etc.) deaf.

adults – even if they have used ASL as their primary language for 40–50 years (Newport, 1984, 1990). This finding highlights two points about the acquisition of morphology: (1) morphology-learning appears to be sensitive to age of acquisition, with mastery of the system associated with early (native) acquisition; (2) since second-generation deaf children (who master ASL morphology completely) often receive their linguistic input from their first-generation deaf parents who may *not* have fully mastered the system, morphology-learning during the early years appears to be relatively insensitive to the nature of input (Singleton & Newport, 1994). These observations highlight both the fragility and the resilience of morphology-learning. In this study, we explore the resilience of morphology generation in the gesture systems created by four deaf children of hearing parents.

2. Method

2.1. *Subjects*

Deaf children born to deaf parents and exposed from birth to a conventional sign language such as ASL acquire that language naturally; that is, these children progress through stages in acquiring sign language similar to those of hearing children acquiring a spoken language (Newport & Meier, 1985). However, as described above, 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 limited linguistic skills in speech (Conrad, 1979; Meadow, 1968). Moreover, although many hearing parents of deaf children send their children to schools in which one of the manually coded systems of English is taught, some 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.

The subjects of this study 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 ASL or to a manual code of English. As preschoolers in oral schools for the deaf, the children spent very little time with the older deaf children in the school who might have had some knowledge of a conventional sign system (i.e., the preschoolers only attended school a few hours a day and were not on the playground at the same time as the older children). In addition, the children's families knew no deaf adults socially and interacted only with other hearing families, typically those with hearing children. One of the primary reasons we were convinced that the children had had no exposure to a conventional sign system at the time of our observations was that they did not know even the most common lexical items of ASL or Signed English (i.e., when a native deaf signer reviewed our tapes, she found no evidence of any conventional signs; moreover, when we informally presented to the children common signs such as those for mother, father, boy, girl, dog, we found that they neither recognized nor understood any of these signs).

The children were videotaped in their homes during free-play sessions which lasted as long as the child was cooperative, typically an hour or two. A large bag of toys, books, and puzzles served as the catalyst for communication (see Goldin-Meadow, 1979). The children were observed over varying periods of time, depending upon when the child first came to our attention. Table 1 presents the number of observation sessions analyzed in this study for each child and the child's age at each of those sessions.[3]

2.2. Coding procedures

2.2.1. Criteria for identifying and interpreting a gesture

The children's videotapes were coded initially according to a gesture transcription system described in detail in Goldin-Meadow (1979). Our criteria for isolating gestures grew out of a concern that the gestures meet

Table 1
Number of observation sessions and age at each session

Child	I	II	III	IV	V	VI	VII
David	2;10	2;11	3;0	3;3	3;5	3;11	4;10
Marvin	2;11	3;1	3;4	3;7	3;9	4;2	4;6
Kathy	3;1	3;4	3;7	3;11	4;0	4;2	4;9
Abe	2;10	3;0	3;2	3;5	3;7	3;9	4;11

[3] We analyzed data from seven sessions for each child between the ages of 2;10 and 4;11. The data are thus a subset of the videotapes collected in our longitudinal study. The sessions are numbered consecutively in Table 1. As a result, the session numbers in this report do not necessarily coincide with the session numbers in previous descriptions of these children's gesture systems (cf. Goldin-Meadow & Mylander, 1984).

the minimal requirements for a communicative symbol and were as follows: (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 must not itself be a direct manipulation of some relevant person or object (i.e., it must be empty-handed, cf. Petitto, 1988). (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).[4]

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 which 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.

Of course, at times the children moved too far afield for their gestures to be interpretable even in context. A small percentage of each child's characterizing gestures could not be interpreted and thus were coded as ambiguous: 4% of 915 gestures for David, 8% of 729 for Marvin, 4% of 582 for Kathy, and 6% of 816 for Abe. In general, reliability between two

[4] 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, Volterra, Bates, Benigni, Bretherton, and Camaioni (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 Petitto, 1988, and Acredolo & Goodwyn, 1988, whose studies of gesture in hearing children are based on criteria that are very close to those used here).

independent coders was high: intercoder agreement ranged between 87% and 91% for identifying and describing gestures, and between 93% and 95% for assigning lexical meanings to individual gestures.

2.2.2. *Coding characterizing gestures*

As described above, characterizing gestures comprise the data base for this study.[5] The form of each characterizing gesture captures an aspect of its referent; for example, the gesture BEAT (two fists alternately arcing back and forth in the air) resembles the act of beating a drum (without the drumsticks in hand). In previous work, we have shown that the deaf children's characterizing gestures functioned as word-like elements within their gesture sentences, at times serving noun-like roles and at other times verb-like roles (Goldin-Meadow, Butcher, Mylander, & Dodge, 1994). Characterizing gestures that were used to focus attention on the discourse topic were considered nouns, while characterizing gestures used to comment on that topic were considered predicates – verbs, if the particular comment described an action. Moreover, gestures playing noun-like roles were distinguished from those playing verb-like roles in two ways – by the form of the gesture, and by its position in a gesture sentence. The distinction between nouns and verbs is most strikingly seen in gestures used in both roles. For example, if the child used a TWIST gesture to focus attention on a jar as the discourse topic (i.e., as a noun), the gesture was likely to be abbreviated in form (one twist of the hand rather than several) and was likely to *precede* a deictic pointing gesture at the jar. If, on another occasion, that same stem TWIST was used to say something about the jar (i.e., as a verb predicate), the gesture was likely to be inflected in form (produced in a space near the jar, the patient of this particular predicate, rather than in neutral space) and was likely to *follow* a deictic pointing gesture at the jar. In the present study, we focus on the *stems* of the children's characterizing gestures; that is, on the basic form of each gesture before it is marked as a noun or a verb.

The gesture stems that the children produced can be described in terms of the two primary components that comprise each stem: the trajectory of the

[5] In addition to characterizing gestures whose forms capture an aspect of their referents, the children also used certain stereotyped gestures commonly found in our culture in which gesture form was less transparently related to meaning. For example, all of the children extended a flat palm to request the transfer of an object; this gesture was used to request relocation to a variety of places and was *not* limited to requesting transfer of an object to the child's own hand. As another example, several children held two fists together side-by-side and then broke the fists apart to indicate that an object was or had been broken, regardless of the motion actually used to break the object. These conventional gestures were comparable to the "frozen" signs of ASL – signs whose stems are unanalyzable and monomorphemic (cf. Kegl, 1985), and thus were eliminated from the analyses. David produced 238 tokens of conventional gestures (26% of his total gestures), Marvin produced 163 (22% of the total), Kathy produced 215 (37% of the total), and Abe produced 228 (28% of the total).

motion, and the shape of the *hand*. We therefore coded the *form* of each gesture in terms of these two components. The trajectory of the motion of a gesture typically pictured the action that the child was attempting to convey with that gesture (as inferred from context; e.g., a circular motion used to describe a car going in a circle),[6] while the shape of the hand typically pictured some aspect of the object involved in the action (e.g., a C-handshape used to describe a turtle moving along a path). We therefore coded the *meaning* of each gesture in terms of the action the child was conveying and the object involved in that action. For example, we coded the TWIST gesture stem in terms of the action "twist" and the object "jar". When used as a noun to identify the jar, the object information in the stem was highlighted (e.g., a twistable-jar) and when used as a verb to request that the jar be twisted, the action information was highlighted (e.g., to jar-twist). Although we focus here on the formation of the stem independent of its role as noun or verb, it is important to note that the descriptions that appear in the Results section do *not* differ for gestures that function as nouns versus verbs. In other words, gestures that function as nouns in a child's gesture system are derived from stems that are identical to the stems of gestures that function as verbs in that child's system.

Because the system that we used to code both forms and meanings of characterizing gestures is central to our findings, we describe the details of the coding system in the Results. However, we note here that our coders were able to use this system reliably: reliability between two independent coders ranged from 85% to 95% agreement for coding handshape (form and meaning) and from 83% to 93% agreement for coding motion (form and meaning).

3. Results

3.1. Initial coding of handshape forms and meanings

3.1.1. Coding handshape forms

We coded five basic handshape forms: Fist, O (thumb close to or touching fingers), C (thumb several inches from the fingers), Palm, and Point. In addition, we coded three other handshapes which were used far less frequently: Thumb, V (two fingers extended and spread), and L (the thumb and index finger extended and at right angles). Handshape forms were described in terms of three parameters: (1) shape of the palm and fingers; (2) breadth of the palm (determined by the presence or absence of spread between the fingers for the Palm handshape or by the number of fingers

[6] The children produced some gestures whose motions traced the outline or extent of an object. These gestures are not included in the analyses presented here. David produced 68 such gestures, Marvin produced 88, Kathy produced 65, and Abe produced 107.

extended for the O and C handshapes); and (3) distance between the fingers and the thumb. We found that there was no variation in the way the children used four of the handshapes (Fist, Thumb, V, and L). However, the remaining four handshapes (O, C, Palm, and Point) varied on one or more of the three parameters.

The handshapes that the children produced are displayed in Table 2. As can be seen in the table, the O and the C varied in three parameters: (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 inch between the fingers and thumb; for the C, the distance was *medium* with 1–3 inches between the fingers and thumb, or *large* with greater than 3 inches between the fingers and thumb); (2) in shape (with the palm and fingers *curved* or *angled*); and (3) in the number of fingers extended (*broad* with four fingers extended, or *skinny* with one or two fingers extended). Thus, there were eight variants of the O handshape, and eight 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 *skinny* without spread). There were thus six variants of the Palm 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, a total of 28 different handshape forms were found in the children's gestures.

All four children were found to produce instances of the five major handshapes (Fist, O, C, Palm, and Point) and instances of most of the 28 different handshape forms: David produced 25 of the 28 forms, Kathy produced 24, Marvin produced 22, and Abe produced 20.

3.1.2. Coding handshape meanings

The essential question underlying our handshape analysis is whether each child's handshape forms map in any systematic way onto categories of meanings. To address this question, we needed a procedure for coding handshape meanings. From the outset, we found that the children used their handshapes in three distinct ways: (1) to represent a HAND as it manipulates an object; (2) to represent the OBJECT itself; or (3) to TRACE the path of motion without representing any aspect of the object involved; these TRACE handshapes were generally 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. David produced 22 TRACE handshapes, accounting for 5% of his total handshapes, Marvin produced 66 (19%), Kathy produced 55 (23%), and Abe produced 56 (16%).

HAND and OBJECT handshapes in the deaf children's gestures are reminiscent of handle classifiers and of semantic or size-and-shape classifiers, respectively, in ASL (cf. McDonald, 1982; Schick, 1987). As an example of a HAND handshape, to describe a cap, one child produced a

Table 2
List of handshape forms in terms of three form parameters

	Basic handshape form	Parameters of form[a] Thumb–finger distance[b]	Palm shape	Hand breadth[c]
1.	O_1	Touch	Curved	Skinny
2.	O_2	Touch	Curved	Broad
3.	O_3	Touch	Angled	Skinny
4.	O_4	Touch	Angled	Broad
5.	O_5	Small	Curved	Skinny
6.	O_6	Small	Curved	Broad
7.	O_7	Small	Angled	Skinny
8.	O_8	Small	Angled	Broad
9.	C_1	Medium	Curved	Skinny
10.	C_2	Medium	Curved	Broad
11.	C_3	Medium	Angled	Skinny
12.	C_4	Medium	Angled	Broad
13.	C_5	Large	Curved	Skinny
14	C_6	Large	Curved	Broad
15.	C_7	Large	Angled	Skinny
16.	C_8	Large	Angled	Broad
17.	$Palm_1$		Straight	Skinny
18.	$Palm_2$		Straight	Broad
19.	$Palm_3$		Curved	Skinny
20.	$Palm_4$		Curved	Broad
21.	$Palm_5$		Angled	Skinny
22.	$Palm_6$		Angled	Broad
23.	$Point_1$		Straight	
24.	$Point_2$		Curved	
25.	Fist			
26.	Thumb			
27.	V			
28.	L			

[a]Thumb–finger distance = distance between the thumb and the fingers; Palm shape = shape of the palm and fingers; Hand breadth = breadth of the palm, described in terms of the number of fingers extended (for the O and C handshapes) or the presence/absence of spread between the fingers (for the Palm handshape).
[b]Touch = fingers touch thumb; Small = fingers <1 inch from thumb; Medium = fingers 1–3 inches from thumb; Large = fingers >3 inches from thumb.
[c]Skinny = one finger for the O and C handshape forms, and no spread between the fingers for the Palm; Broad = four fingers for the O and C handshape forms, and spread between the fingers for the Palm.

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 OBJECT handshape. The same handshape could be used to represent either a HAND 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 [HAND]. 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].[7]

For both the HAND and OBJECT handshapes, we began our analyses with a set of meaning distinctions discovered on the basis of our previous analyses of one deaf child's gesture system, David (cf. Goldin-Meadow & Mylander, 1990b). In this previous work, we listed all of the objects that David used a particular handshape in relation to. We then surveyed those objects and asked whether the set had attributes in common. If so, we took that common set of attributes to be the meaning associated with that particular handshape. For example, David used the Fist handshape as a HAND for objects which had in common that they were <2 inches in width and >3 inches in length, but used the Fist handshape as an OBJECT for objects which had in common that they were bulky. On the basis of these analyses, we amassed a set of characteristics which we then used to code the objects about which the children gestured.

3.2. Determining the unit of analysis appropriate to each child's handshapes

Our next task was to determine the form and meaning categories that were appropriate to each child's gesture system. The iconic properties of gesture permit one to vary the shape of the hand to fit the particular characteristics of each object described. For example, a child could make fine distinctions in the distance between the thumb and finger (a form parameter) to capture subtle differences in how one would hold an object $\frac{1}{2}$ inch in diameter, 1 inch in diameter, 2 inches in diameter, and so on (a

[7] Orientation of the hand with respect to the motion was crucial in determining whether the hand represented a HAND 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 HAND handshape rather than an OBJECT handshape. There were, of course, instances where it was impossible to tell whether the hand was a HAND or an OBJECT handshape. These cases, which comprised no more than 1% of each child's gestures, were considered ambiguous and excluded from the analyses of handshape.

parameter). Our hope was that the system we used to code the forms and meanings of each child's gestures was sufficiently fine-grained so that the units we coded would turn out to be *smaller than* the units the children actually used in their gesture systems. In this way, if we were to find that the children used their handshapes categorically, the categories would not be forced by our coding system but instead would reflect the way the children actually used their handshapes.

In fact, we found that the units we used to code the children's gestures did appear to be small enough to capture each child's system. We describe the analyses that led to this conclusion first for HAND handshapes and then for OBJECT handshapes, using data from one child (David). We present data from a single child at this stage of the analyses because the tables are so cumbersome. It is important to note, however, that we conducted the same analyses on the other children's handshapes and found patterns identical to those described below.

3.2.1. Determining form and meaning units in HAND handshapes

We considered three meaning dimensions, each of which could have been conveyed by one of the three form parameters displayed in Table 2.[8] When a hand *actually* grasps an object, the hand is molded to the object along at least three dimensions: the distance between the thumb and fingers is determined by the width of the grasped object; the shape of the palm is determined by the shape of the object; and the breadth of the palm is determined by the length of the object. However, when *representing* a hand grasping an object, the hand need not conform to all (or even any) of these characteristics of the object. In order to determine whether David captured these characteristics of the object in his handshape forms, we sorted his handshape forms three times and examined each sort against one of the three object characteristics. Table 3 presents a subset of David's HAND handshapes (the Fist, O, and C) displayed three times. (1) In the first panel, the forms are listed according to variations in the thumb–finger distance, and are displayed in relation to the width of the object about which the child was gesturing. (2) In the second panel, the same forms are listed but now according to variations in the shape of the palm, and are displayed in relation to the shape of the object. (3) In the third panel, the forms are listed according to the breadth of the hand, and are displayed in relation to the length of the object.

Three points are evident from Table 3. First, David systematically mapped hand forms onto hand meanings. However, he did so only for one

[8] We explored these particular meaning dimensions because they could be mapped in a relatively transparent fashion onto the form parameters displayed in Table 2. It is, of course, possible that the deaf children conveyed other meaning dimensions in their gestures. What we show below is that the children conveyed *at least* these meanings and that they did so using particular handshape forms.

Table 3

David's Fist, O, and C HAND forms displayed in relation to three different meaning dimensions[a]

HAND forms in relation to the width of the object[b]

Hand form	T–F distance	Palm shape	Hand breadth	Object width (inches) 0–1	1–2	2–3	3–5	>5
Fist				43	30	5		
O	T	C	Sk					
	T	C	B	2	1			
	T	A	Sk	18	2			
	T	A	B	46	6	1		
O	Sm	C	Sk					
	Sm	C	B		3			
	Sm	A	Sk	2				
	Sm	A	B	1				
C	M	C	Sk					
	M	C	B		1	2	1	
	M	A	Sk					
	M	A	B		1	2		
C	L	C	Sk			1		
	L	C	B			5	1	
	L	A	Sk					
	L	A	B			1	3	

HAND forms in relation to the shape of the object[b]

Hand form	T–F distance	Palm shape	Hand breadth	Object shape[c] Blky	Rnd	Ang	Cvd	Str	Irr
Fist					38			1	2
O	T	C	Sk						
	T	C	B		3				
	Sm	C	Sk						
	Sm	C	B				1	2	
O	T	A	Sk		3		3	1	
	T	A	B		39		3	2	1
	Sm	A	Sk		1				
	Sm	A	B						
C	M	C	Sk						
	M	C	B		2		1	1	
	L	C	Sk		1				
	L	C	B		1			4	1
C	M	A	Sk						
	M	A	B		1		1	1	
	L	A	Sk						
	L	A	B		2			2	

HAND forms in relation to the length of the object[b]

Hand form	T–F distance	Palm shape	Hand breadth	Object length (inches) 0–1	1–2	2–3	3–5	5–10	>10
Fist					2	3	10	20	43
O	T	C	Sk						
	T	A	Sk	2	1		3	9	5
	Sm	C	Sk						
	Sm	A	Sk	1				1	
O	T	C	B				2	1	
	T	A	B	3	1	5		7	37
	Sm	C	B		2	1			
	Sm	A	B					1	
C	M	C	Sk						
	M	A	Sk						
	L	C	Sk			1			
	L	A	Sk						
C	M	C	B			1	2		1
	M	A	B			1		2	
	L	C	B			4	1		1
	L	A	B		1		2	1	

[a] Note that the hand forms appeared to be systematically associated with the hand meanings only in the first panel of the table. David used variations in thumb–finger distance to convey differences in the width of the grasped object but *did not* use palm shape or hand breadth to capture differences in the shape or length of the object.

[b] The abbreviations used for the form categories are: T–F distance = distance between the thumb and fingers; T = touch; Sm = small; M = medium; L = large; C = curved; A = angled; Sk = skinny; B = broad.

[c] The abbreviations used for the meaning categories for Object shape are: Blky = bulky; Rnd = round; Ang = angled; Cvd = curved; Str = straight; Irr = irregular. There are fewer numbers in this panel (HAND forms displayed in relation to the shape of the object) than in the other two panels because the diameter of some of the objects was too small to be meaningfully described in terms of shape.

of the three meaning dimensions: he used variations in *thumb–finger distance* to convey differences in the width of the grasped object, but did not use palm shape or hand breadth to capture differences in the shape or length of the object. For example, note in the first panel of the table that David used the Fist, OTouch, and OSmall handshapes for objects narrow in width, the CMedium for objects that were somewhat wider, and the CLarge for objects that were wider still. In contrast, in the second panel of the table, note that even though David did use Curved handshapes (both O's and C's) for objects that actually were curved in shape, he was just as likely to use these Curved handshapes for objects that were round or straight. We analyzed all of David's HAND handshapes in this manner and, on the basis of these data, decided that *meaning* in these handshapes was most appropriately analyzed in terms *object width*.

The second point to notice in Table 3 is that, in the first panel of the table, David tended to use variants within a particular form category for objects of the same width. For example, he used the OTouch handshape – independent of whether its palm shape was Curved or Angled, or its hand breadth was Skinny or Broad – for objects with widths ranging from 0 to 2 inches. On the basis of these analyses, we decided that *form* in David's HAND handshapes was most appropriately analyzed in terms of the larger units, *OTouch, OSmall, CMedium, CLarge*, etc., rather than the smaller units, OTouch-Curved-Skinny, OTouch-Curved-Broad, OTouch-Angled-Skinny, etc.

The final point to note in Table 3 is that the consistent mappings between form and meaning (in the first panel of the table) depend on units larger than the units we coded. Specifically, David used the Fist, three variants of the OTouch, and three variants of the OSmall to describe objects 0–1 inch in width and objects 1–2 inches in width. Note that the Fist, the OTouch, and the OSmall handshapes do vary in form and thus would not be used to manipulate the same set of objects in the real world. These three hand forms could easily have been used to make distinctions between objects <1 inch and objects 1–2 inches in diameter. However, the forms were not used in this way, suggesting that the child did not necessarily use *in his gestures* the handshapes that he would have used to actually grasp these objects. Thus, the child appeared to be using his hand forms categorically to map onto meanings, and those categories were not dictated by the level at which we coded either forms or meanings.

3.2.2. Determining form and meaning units in OBJECT handshapes

We determined the appropriate meaning and form units for the children's OBJECT handshapes in the same manner. As an example, Table 4 presents the same handshapes (the Fist, O, and C) for David but this time used as OBJECT handshapes. The 17 hand forms are again displayed three times in terms of the three form and three meaning parameters (see the description of Table 3 above). We see in Table 4 that David systematically mapped his

OBJECT hand forms onto hand meanings, and again he did so only for one of the three dimensions. However, unlike his use of HAND forms, David used variations in the *shape of the palm* to convey differences in the shape of the grasped object. Variations in the way he used thumb-finger distance or hand breadth did not systematically map onto variations in the width or length of the objects gestured about. We analyzed all of David's OBJECT handshapes in this manner and, on the basis of these data, decided that *meaning* for these handshapes was best analyzed in terms of *object shape*.

Note also in the middle panel of Table 4 that (although the numbers are small) David tended to use variants within a particular handshape form category for the same type of objects. For example, he used the OCurved handshape – independent of whether its thumb–finger distance was Touch or Small, or its hand breadth was Skinny or Broad – for round objects. On the basis of these analyses, we decided that *form* in David's OBJECT handshapes was best analyzed in terms of the larger units, *OCurved*, *OAngled*, *CCurved*, *CAngled*, *Palm Curved*, etc., rather than the smaller units, OCurved-Touch-Skinny, OCurved-Touch-Broad, OCurved-Small-Skinny, etc.

We conducted these handshape analyses separately for HAND and OBJECT handshapes for each of the four children. As in the analyses for David, we found, for each child, that *meaning* was most appropriately analyzed in terms of object width for HAND handshapes and object shape for OBJECT handshapes, and that *form* was most appropriately analyzed in terms of the larger units for both HAND (i.e., OTouch, OSmall, CMedium, etc.) and OBJECT (OCurved, OAngled, CCurved, etc.) handshapes. In addition, the analyses of each child's data made us confident that the units we used to code the child's gestures were small enough to capture (but not force) categorical mappings of forms and meanings in each child's gesture system. In the next sections, we use the form and meaning units isolated here as the starting point for determining form-meaning mappings in each child's handshapes. We focus first on HAND handshapes and then on OBJECT handshapes.

3.3. Form–meaning pairings in HAND handshapes

3.3.1. The procedure for identifying form–meaning pairings

None of the children used the V or L hand form as a HAND handshape. As a result, our analyses of HAND forms were performed on the remaining eight forms. For each child, we displayed on the left side of a grid the eight hand forms (organized in terms of thumb–finger distance since, as described above, this was the relevant form parameter for HAND handshapes for all of the children, cf. Table 3). Across the top of the grid, we listed object widths, the meaning dimension found to be relevant to HAND 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). Objects

Table 4

David's Fist, O, and C OBJECT forms displayed in relation to three different meaning dimensions[a]

OBJECT forms in relation to the width of the object[b]

Hand form	T–F distance	Palm shape	Hand breadth	Object width (inches) 0–1	1–2	2–3	3–5	>5
Fist					3			
O	T	C	Sk	2		1		
	T	C	B		4			1
	T	A	Sk				1	
	T	A	B				4	1
O	Sm	C	Sk	1				
	Sm	C	B					
	Sm	A	Sk					
	Sm	A	B					
C	M	C	Sk					
	M	C	B				4	
	M	A	Sk					
	M	A	B					
C	L	C	Sk					
	L	C	B			1		
	L	A	Sk					
	L	A	B		1		2	

OBJECT forms in relation to the shape of the object[b]

Hand form	T–F distance	Palm shape	Hand breadth	Object shape[c] Blky	Rnd	Ang	Cvd	Str	Irr
Fist				3					
O	T	C	Sk		3				
	T	C	B		4	1			
	Sm	C	Sk		1				
	Sm	C	B						
O	T	A	Sk		1				
	T	A	B				5		
	Sm	A	Sk						
	Sm	A	B						
C	M	C	Sk						
	M	C	B				4		
	L	C	Sk						
	L	C	B				1		
C	M	A	Sk						
	M	A	B						
	L	A	Sk						
	L	A	B				3		

OBJECT forms in relation to the length of the object[b]

Hand form	T–F distance	Palm shape	Hand breadth	Object length (inches) 0–1	1–2	2–3	3–5	5–10	>10
Fist					1	2			
O	T	C	Sk	2		1			
	T	A	Sk				1		
	Sm	C	Sk	1					
	Sm	A	Sk						
O	T	C	B				4	1	
	T	A	B				4	1	
	Sm	C	B						
	Sm	A	B						
C	M	C	Sk						
	M	A	Sk						
	L	C	Sk						
	L	A	Sk						
C	M	C	B		2			2	
	M	A	B						
	L	C	B			1			
	L	A	B		1			2	

[a] Note that the hand forms appeared to be systematically associated with the hand meanings only in the middle panel of the table. David used variations in palm shape to convey differences in the shape of the object but did not use thumb–finger distance or hand breadth to capture differences in the width or length of the object.

[b] The abbreviations used for the form categories are: T–F distance = distance between the thumb and fingers; T = touch; Sm = small; M = medium; L = large; C = curved; A = angled; Sk = skinny; B = broad.

[c] The abbreviations used for the meaning categories for Object shape are: Blky = bulky; Rnd = round; Ang = angled; Cvd = curved; Str = straight; Irr = irregular.

were classified into 1 inch batches since this was as fine a distinction as we felt we could reliably make when coding the videotapes.

As an example, Table 5 displays the HAND grid for David. The numbers enclosed in boxes in the table represent the consistent pairings of forms and meanings in David's HAND handshapes that is, his HAND morphemes. We used the following procedure to identify morphemes in the children's handshapes. To determine whether a particular hand form was consistently used for a particular meaning (e.g., whether the Fist form was used consistently enough for objects 0–1 inch in width for this particular form-meaning pairing to be considered part of David's morphemic system), we first determined the two most frequent forms used for each meaning (e.g., for objects 0–1 inch 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 objects 0–1 inch in width and objects 1–2 inches in width, in that order).[9] The final step was to survey the grid and isolate those cells which contained *both* a frequent form and a frequent meaning (e.g., the Fist

Table 5
David's grouped HAND forms displayed in relation to the width of the manipulated object[a]

Hand form	Object width (inches)					Many small surfaces
	0–1	1–2	2–3	3–5	>5	
Point	3					
Thumb	1					
Fist[b]	43	30	5			
OTouch	66	9	1			
OSmall	3	3				
CMedium		2	4	1		
CLarge			7	4		
Palm	1	4		10	11	3

[a] The numbers enclosed in the boxes represent the form–meaning pairings that met our criterion for consistent use; that is, the form–meaning pairings considered to be HAND morphemes (see text).
[b] The Fist handshape was distinguished from the OTouch and OSmall in David's gesture by length; David used the Fist for object >3 inches in length but the O forms for objects of any length.

[9] 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.

was a frequent form for the 0–1 inch wide meaning, and vice versa). These cells were considered to be consistent form–meaning pairings for that child. In other words, the cells in which the most frequent forms *intersected* with the most frequent meanings were classified as consistent form–meaning pairings. We followed this procedure for all of the cells in a child's grid.[10]

Note that, in Table 5, the Fist, OTouch, and OSmall handshapes appear to be indistinguishable from one another in terms of their width meanings. These three handshapes might therefore be allomorphs of a single morpheme. However, before classifying these handshapes as allomorphs, we examined the distribution of these handshapes for the other two meaning dimensions: length and shape of the object. We found, in fact, that David did use these three handshapes differently with respect to the length of objects. In particular, David used the OTouch and OSmall handshapes for objects 0–2 inches in diameter that varied in length (all the way from <1 to >10 inches in length); in contrast, David used the Fist handshape more restrictively – for objects that were again 0–2 inches in diameter but were also relatively long (>3 inches in length). We therefore added a length restriction to the description of David's Fist handshape; this restriction served to distinguish the Fist from the OTouch and OSmall in David's system. Note, however, that the OTouch and OSmall were still indistinguishable, and therefore were considered allomorphs in David's system. In general, if two hand forms were indistinguishable when we examined the width dimension, we examined the length and shape dimension to see if there were any differences in the way the two forms were used. If so, we added that restriction to the description of the relevant handshape; if not, we considered the two handshapes to be allomorphs of a single morpheme.

Our procedure for identifying form–meaning mappings in the HAND handshapes may appear to be somewhat arbitrary. We felt the need for a procedure, albeit an arbitrary one, so that we could be certain that we were applying the same standard to each child's gestures. Rather than decide on

[10] 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 0–1 inch in Table 3 is the most frequent meaning for the Point form (indeed, it is the only meaning for this form), but the Point is *not* one of the top two forms used for this meaning (Fist and OTouch are). The Point/0–1 inch 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 Point with no associated meaning, we arbitrarily assigned the Point its most frequent meaning (0–1 inch) and added the pairing to the list of David's morphemes. In general, when a form turned out to be associated with no meaning at all, we assigned that form its most frequent meaning; similarly, when a meaning turned out to be associated with no form, we assigned that meaning its most frequent form. 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), no matter how infrequently, it would be assigned a meaning (or form) in the child's system.

an intuitive basis that a particular form was associated with a particular meaning in the child's system, we chose to make the decision on the basis of an arbitrary procedure. It is worth noting that the criterion we have adopted, when applied to David's handshapes, results in form–meaning pairings that resemble those generated by the more flexible process we used in our previous work (cf. Goldin-Meadow & Mylander, 1990b). The criterion we have adopted in this study has the advantage that, whatever its validity, it can be reliably and consistently applied to each child's gestures.[11] In addition, note that our procedure does not force *coherent* form–meaning pairings on the data if they are not there (as we will see in Study 2 in our analyses of the gestures that the deaf children's mothers produced). The crucial test in determining whether each child's handshapes form a morphological system is two-fold: (1) whether, using our procedure, we arrive at coherent form–meaning pairings for the handshapes of each of the four children; *and* (2) whether a sizeable number of the gestures each child produces fits the form–meanings we devised for that child.

3.3.2. The resulting form–meaning pairings for all of the children

Table 6 presents the form–meaning pairings for the HAND morphemes for each of the four 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 Point and Thumb handshapes were used for objects with very small widths, the Fist and the O handshapes were used for objects with slightly larger widths, the C handshapes were used for objects with yet larger widths, and the Palm handshape was used for objects with the largest widths. In addition, each of the four children used the Palm handshape a few times for a set of objects with very small surfaces (e.g., piano keys; note, however that each child tended to use the Palm in this way for a single type, suggesting that this may not have been a productive form for any of the children).

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

[11] We chose this criterion in order to filter out the noise of infrequent associations between a form and a meaning. We have analyzed all of the data with more stringent and less stringent criteria and, although the details of the analyses change, the basic phenomenon – that the children's gestures form coherent systems which differ from their mothers' – remains.

to suggest that the deaf children were mapping handshapes onto meanings in an analog rather than a discrete fashion.[12] 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. For example, within the category of objects 0–2 inches wide in David's gestures, objects that are 0–1 inch wide and objects that are 1–2 inches are *both* conveyed by any one of three handshapes that vary quite perceptibly in thumb–finger distance (Fist, OTouch, OSmall, cf. Table 5); the smaller meaning (0–1 inch) is *not* most likely to be conveyed by the smallest form (Fist), nor is the larger meaning (1–2 inches most likely to be conveyed by the largest form (OSmall; see Supalla, 1982, p. 126, for discussion of this point with respect to ASL).

The bottom of Table 6 also 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 HAND handshapes. Exceptions for each of the children consisted of form–meaning mismatches. For example, David used a Fist form for an object 0–2 inches in width but *<3 inches in length*, that is, for a knob on a toy; OTouch or OSmall would be the appropriate form for this object in David's system.

Although the children's HAND morphemes resembled one another at a general level, they did differ in detail. For example, the OTouch handshape was used by all four of the children for narrow objects; however, the precise boundary for a narrow object differed across the children: for David, Marvin and Kathy, the boundary for this handshape was 2 inches (i.e., they used the OTouch for objects 0–2 inches in width) while, for Abe, the

[12] In this regard, it is important to point out that the children's HAND morhemes were not always accurate representations of the way a hand manipulates a particular object in the real world. For example, David used the same HAND form (the Fist) to describe manipulating a balloon string, a newspaper, a flag pole, a string of tree lights, the brim of a hat, and an umbrella handle – objects that would be handled quite differently in the real world; these objects might or might not be manipulated with the hand in a fist and, even if a fist were used, the tightness of the fist would vary across the set of objects. Nevertheless, David used the same hand form, the Fist, and without any variation in the tightness of the handshape, when gesturing about these objects. Thus, David did not distinguish objects of varying widths within the Fist category. However, he did use his handshapes to distinguish objects with narrow widths *as a set* from objects with larger widths (>2 inches; e.g., a cup, a guitar neck) which were conveyed either by a CMedium or a CLarge hand. The child thus appeared to consign handshapes to discrete categories, rather than utilize analog representations of "real world" objects.

Table 6
Children's hand morphemes[a]

Forms	David's meanings	Marvin's meanings	Kathy's meanings	Abe's meanings
Point Thumb	Handle a surface <1 inch wide e.g., gun trigger 3(4)	Handle a surface <1 inch wide e.g., typewriter key 4(15)	Handle a surface <1 inch wide e.g., button 6(14)	Handle a surface <1 inch wide e.g., tip of animal's tail 5(7)
Fist	Handle an object 0–2 inches wide and >3 inches long e.g., balloon string 19(70)	Handle an object 0–2 inches wide e.g., steering wheel 40(82)	Handle an object 0–2 inches wide and >3 inches long e.g., fishing pole 18(27)	Handle an object 0–2 inches wide e.g., bubble jar lid 19(27)
OTouch	Handle an object 0–2 inches wide e.g., bandaid 31(96)		Handle an object 0–2 inches wide e.g., penny 16(30)	Handle an object 0–1 inch wide e.g., tiny knob 26(37)
OSmall		Handle an object 0–2 inches wide and <2 inches long e.g., jar lid 7(16)	Handle an object 1–2 inches wide e.g., jar lid 4(14)	Handle an object 1–2 inches wide banana 1(3)
CMedium	Handle an object 2–3 inches wide e.g., cup 3(4)	Handle an object 2–3 inches wide e.g., box 4(6)		Handle an object 1–2 inches wide and 1–5 inches long e.g., toy soldier 6(8)
CLarge	Handle an object 2–5 inches wide e.g., horn 7(11)	Handle an object 2 to >5 inches wide e.g., bowling ball 11(16)	Handle an object 2–3 inches wide e.g., puzzle envelope 2(2)	Handle an object 2–3 inches wide horn 1(1)
Palm	1. Handle a surface 3 to >5 inches e.g., drawer 11(23) 2. Handle many small surfaces piano keys 1(3)	1. Handle a surface 3 to >5 inches e.g., drawer 6(9) 2. Handle many small surfaces knife points 1(2)	1. Handle a surface 3 to >5 inches e.g., face 8(9) 2. Handle many small surfaces piano keys 1(1)	1. Handle a surface 3 to >5 inches e.g., drum 7(21) 2. Handle many small surfaces piano keys 1(1)
Proportion of gestures fitting the system	.91 ($N = 232$)	.91 ($N = 161$)	.81 ($N = 120$)	.86 ($N = 122$)

[a] 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).

boundary was 1 inch (he used the OTouch for objects 0–1 inch in width). In addition, the relationship of particular morphemes to other morphemes in the system differed across the children. For example, in Kathy's and Abe's systems, OTouch was a category unto itself and was distinct in meaning from the other forms each child used. In contrast, in Marvin's system, OTouch was not distinguished from the Fist handshape (both were used for objects 0–2 inches in width and thus formed a single category for Marvin) while, in David's system, OTouch was not distinguished from OSmall (these two handshapes were both used for objects 0–2 inches in width and thus formed a single category for David). The similarities across the children's systems in the meanings of the handshape forms are not surprising given that the systems had to have been relatively transparent in order to have been understood by the hearing individuals who communicated with the deaf children. The differences across the systems suggest that, within the general constraint of iconicity, the children were able to introduce relatively arbitrary distinctions.

3.4. Form–meaning pairings in OBJECT handshapes

We began our analyses of the children's OBJECT handshapes by constructing the same type of grid that we constructed for the HAND handshapes. For each child, we displayed the hand forms on the left side of the grid, although for this grid, the hand forms were organized in terms of shape of the palm since we found in our initial analyses that palm shape was the relevant form parameter for OBJECT handshapes (cf. Table 4). Across the top, we listed categories for the shape of the object, using the range of categories discovered in our previous analyses of David (cf. Goldin-Meadow & Mylander, 1990b). In addition to the shape categories, we found in our earlier analyses that David used his OBJECT handshapes for two types of objects that varied in shape but had a semantic feature in common – vehicles and animate objects. We therefore included these two semantic categories as possible meanings in each child's OBJECT grid.

As an example, Table 7 displays the OBJECT grid for David. The numbers enclosed in boxes in the table represent the consistent pairings of forms and meanings in David's OBJECT handshapes, that is, his OBJECT morphemes. We used the same procedure to identify form–meaning pairings in OBJECT handshapes as was used for the HAND handshapes, with one exception. There was less variability in the way David (and the other three children) used OBJECT forms and meanings; that is, there tended to be a bigger disparity between the most frequent form (or meaning) and the next most frequent form (or meaning) in the OBJECT handshapes than in the HAND handshapes. As a result, we used a more stringent criterion for including a particular cell in a child's list of OBJECT morphemes. A cell was considered a consistent form–meaning pairing for a grid if the cell contained the most frequent form or the most frequent meaning (paired

Table 7
David's grouped OBJECT forms displayed in relation to *object* meaning categories[a]

Hand form	Bulky object	Round object	Angled object	Curved object	Straight wide object	Vehicle	Animate object	Individuated parts	Straight skinny object	Very small object	L-shaped object	V-shaped object
Fist	3											
OCurved		8	1									
OAngled		1	5									
CCurved				5								
CAngled				3								
PalmCurved					2							
PalmStraight		1	2		39	6	14		1			
PalmAngled			1				2					
PalmBroad								9				
Point				1			1		11	1		
L											3	
V												7

[a] The numbers enclosed in the boxes represent the form–meaning pairs that met our criterion for consistent use; that is, the form–meaning pairs considered to be morphemes (see text).

with each other, or with the second most frequent form or meaning). In other words, we excluded cells which contained the second most frequent form paired with the second most frequent meaning (these cells were included as morphemes in our HAND analyses). We followed this procedure for all of the cells in a child's grid.

Table 7 presents the results of applying this procedure to David's OBJECT handshapes. Note that, in David's OBJECT handshapes, two distinct forms could function as a single category. For example, in David's OBJECT handshapes, the CCurved form was not distinguished from the CAngled (both were used for curved objects) and thus these two forms functioned as a single category. In contrast, the OCurved form was used differently from the OAngled (one was used for round objects, the other for angled objects); these two forms thus functioned as separable and distinct categories in David's gesture system.

Table 8 presents the form–meaning pairings for the OBJECT morphemes for each of the four children. The set of morphemes described for each of the children is, in general, systematic and coherent. However, it should be noted that several of the OBJECT handshapes were used for only one type of object (e.g., the V form, the L form, some of the Point forms). These handshapes may not be productive morphemes in the children's gesture systems but may function as labels for particular objects (e.g., the L form used for guns, or the V form used for scissors; indeed, these two forms may well be conventional gestures within our culture). Table 8 (on the bottom) also 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 are in general high, suggesting that the system described for each child is a good reflection of that child's use of OBJECT handshapes.

As in the children's HAND handshapes, the children's OBJECT morphemes resembled one another at a general level but differed in detail. The Fist used for bulky objects is an example of a morpheme found in all four of the children's systems. As a second example, David, Kathy, and Abe all used the PalmStraight for vehicles (the fourth child, Marvin, used a TRACE handshape whenever he gestured about vehicles). In contrast, the children differed in their use of OAngled: David used it for angled objects, Marvin used it for curved objects, and Kathy and Abe both used it for round objects. In addition, OAngled functioned as a distinct category in David's and Marvin's gestures, while in Kathy's and Abe's gestures it was indistinguishable from OCurved and thus appeared to form a single category with the OCurved. As in the HAND morphemes, the similarities across the children's OBJECT morphemes are not surprising given that the systems needed to be relatively transparent to be effective in communicating with the hearing individuals in the deaf children's worlds. But here again, the small differences across the children's gesture systems point to arbitrariness within the children's (essentially iconic) systems.

Table 8
Children's object morphemes[a]

Forms	David's meanings		Marvin's meanings		Kathy's meanings		Abe's meanings	
Fist	Bulky object e.g., hammer head	2(3)	Bulky object e.g., toy bank	2(3)	Bulky object e.g., bike pedal	2(2)	Bulky object e.g., bell clapper	4(6)
OCurved	Surface of a round object e.g., ball	4(10)	Surface of an object of any shape e.g., bubbles	4(4)	Surface of a round object e.g., camera lens	3(3)	Surface of a round object[b] e.g., Playdoh can	5(9)
OAngled	Surface of an angled object e.g., Santa's hat	2(5)	Surface of a curved object toy head	1(1)				
CCurved	Surface of a curved object e.g., curved block	5(8)	Surface of an angled object e.g., case for toys	2(2)	Surface of a curved object e.g., mask	2(2)	Surface of a curved object e.g., pumpkin	2(2)
CAngled					Surface of an angled object roof	1(1)		
PalmCurved			Curved–wide object flat worm	1(3)	Curved–wide object e.g., claw	2(2)	Curved–wide object turtle shell	1(1)
PalmStraight	Vehicle e.g., airplane	4(8)	Straight–wide object e.g., flag	13(17)	1. Vehicle e.g., helicopter 2. Straight–wide object e.g., puzzle piece	2(2) 7(11)	1. Vehicle[c] e.g., train 2. Straight–wide object e.g., flat board 3. Animate object e.g., seal, mom	2(2) 23(41) 9(16)
PalmStraight or Curved	Straight–wide object e.g., butterfly wings	12(43)			Animate object[d] e.g., cat	4(7)		
PalmStraight or Angled	Animate object e.g., Santa Claus	9(18)	Animate object e.g., frog	5(12)				

Table 8. Continued.

Forms	David's meanings		Marvin's meanings		Kathy's meanings		Abe's meanings	
Palm Broad[e]	Indivuated points or lines e.g., snowflakes	6(9)	Individuated points or lines e.g., bullet spray	2(5)	Individuated points or lines e.g., snowflakes	3(3)	Individuated lines teeth of a comb	1(1)
Point	1. Straight–skinny object e.g., straw	6(11)	1. Straight–skinny object e.g., candle	10(16)	1. Straight–skinny object e.g., wand	4(8)	1. Straight–skinny object e.g., pencil	6(20)
	2. Very small object lip	1(1)	2. Very small object penny	1(2)	2. Very small object penny	1(2)	2. Pointed object tip of a top	1(7)
					3. Surface of round object e.g., balloon	2(2)		
Thumb							Very small object penny	1(2)
V	V-shaped object scissors	1(7)	V-shaped object scissors	1(2)	V-shaped object e.g., tongs	2(3)		
L	L-shaped object gun	1(3)					L-shaped object gun	1(1)
Proportion of gestures fitting the system	.93 ($N = 135$)		.89 ($N = 75$)		.92 ($N = 52$)		.76 ($N = 142$)	

[a] 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).
[b] Abe did not use the full range of OCurved and OAngled forms; he used only forms in which the thumb–finger distance was "touch" rather than "small".
[c] All but one of the PalmStraight forms Abe used for these meaning were broad in form (i.e., the fingers of his palm were spread wide).
[d] Kathy did use one PalmAngled form for an animate object; thus her "animate object" category may not be restricted to the PalmStraight or Curved forms, but may extend across all three palm shapes (Straight, Curved, or Angled).
[e] Marvin used all three palm shapes (Straight, Curved, Angled) in their broad forms for these meanings, but David and Kathy used only Straight and Curved Palms, and Abe used only Curved.

3.5. Initial coding of motion forms and meanings

Motions were coded in terms of the type of trajectory traced by the hand (linear path, arced path, circle) or the motions of the hand in place (revolve, open/close, bend, wiggle). Arcs were further distinguished in terms of length of path (less than 5 inches, between 5 and 10 inches, greater than 10 inches) and directionality (unidirectional vs. bidirectional). We used these particular size categories because they were the smallest divisions that we felt we could code reliably on our videotapes. These distinctions resulted in a set of 11 motion forms, displayed in Table 9. In addition, we also coded the particular joint (elbow, shoulder, wrist), or set of joints, that was used in forming a pivot, a partial revolve, or a full revolve.

To code motion meanings, we used the set of categories established in our previous analyses of David's gesture system (cf. Goldin-Meadow & Mylander, 1990b). We classified each gesture into a meaning category on the basis of the characteristics of the action that the gesture conveyed.

3.6. Form–meaning pairings in motions

As in our handshape analysis, we then established a form-by-meaning grid for each child. All of the motion forms, divided according to the set of joints the child used to form the motion, were listed on the left side of the grid, and the meanings were listed across the top. As an example, Table 10 displays the motion grid for David. As can be seen from the table, David tended to use variants within a particular form category for the same types of meanings. For example, he used the Arc To and Fro motion form to convey back and forth movements – independent of whether the arc was produced with an elbow pivot, a shoulder pivot, a wrist pivot, or any combination of the three. We therefore conducted the rest of our analyses of motions using the larger forms (i.e., the forms described in Table 9).

Table 9
Description of motion forms

Form	Description
Linear Path	Hand moves unidirectionally in a straight path
Long Arc	Hand moves unidirectionally in an arced path >10 inches in length
Medium Arc	Hand moves unidirectionally in an arced path >5 inches and <10 inches in length
Short Arc	Hand moves unidirectionally in an arced path <5 inches in length
Arc To&Fro	Hand moves bidirectionally in an arced path of any length
Circular	Hand moves in circle
Revolve	Wrist or fingers revolve
Open/Close	Hand or fingers open and/or close
Bend	Hand or fingers bend
Wiggle	Fingers wiggle
No Motion	Hand held in place

We used the same procedure that we used to analyze HAND handshapes to identify morphemes in the children's motions. Table 11 presents the results of this analysis for David's motions. The numbers enclosed in the boxes in this table represent the form–meaning pairings that met our criterion for consistent use; that is, the form–meaning pairings identified as motion morphemes in David's gestures. Note that, in David's motions, two distinct forms could function as a single category. For example, in David's motions, the Medium Arc form was not distinguished from the Short Arc form (both were used to convey repositioning to reorient or repositioning to affect an object) and thus these two forms functioned as a single, undifferentiated category. In contrast, the Long Arc form was used differently from the other two arcs, and was most often used to convey changing location in a path with an endpoint; the Long Arc thus functioned as its own distinct category in David's gesture system.

Table 12 presents the form–meaning pairings for the motion morphemes for each of the four children. As found in the analysis of the children's handshapes, the set of morphemes described for each child's motions is systematic and coherent. Table 12 (on the bottom) also 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 lower than for handshapes, are respectable, suggesting that the system described for each child is a good reflection of that child's use of motions. Exceptions for each of the children consisted of form–meaning mismatches. For example, David at times used a Long Arc form to convey changing location by moving in a path *without* an endpoint (rather than with an endpoint); Linear Path would be the appropriate form for this action in David's system.

As in their handshape morphemes, the children's motion morphemes resembled one another at a general level but differed in detail. For example, the Medium Arc and Short Arc forms were used by all four children to convey the meaning "reposition to reorient". However, the children differed in how they used these forms to convey the meaning "reposition to affect an object". In David's system, both the Medium Arc and the Short Arc were used for this meaning. In Marvin's system, the Short Arc alone was used for this meaning and, in Abe's system, the Medium Arc alone was used for this meaning. Kathy used a different form entirely (Linear Path) to convey the "reposition to affect an object" meaning.

3.7. *Is orientation conflated with motion or is it a separable morpheme?*

In our analyses of motion, we coded the trajectory of motion as though it were a component isolable from the rest of the movement. Indeed, the fact that we could reliably code trajectory suggests that, at some level, it *is* a separable component – at least from the transcriber's point of view. The question we now address is whether there is evidence that trajectory is an isolable unit for the child as well as for the experimenter. Note that while

Table 10
David's motion forms displayed in relation to motion meaning categories[a]

Motion form		Motion meaning												
Trajectory	Joint motion[b]	Change location in path		Reposition to reorient	Reposition to affect object	Move back/forth	Move in circle	Rotate	Open/close	Expand/contract	Bend	Wiggle	Hold	Exist
		No endpoint	Endpoint											
Linear Path	pivot es	10	7	2		1								
	pivot we		3											
	pivot ws	2												
	pivot wes	3	11		1	1								
Long Arc	p-rev es		2											
	pivot e			1										
	pivot s			1										
	pivot w		1											
	pivot es	1	5	4	1									
	pivot we													
	pivot ws	1												
	pivot wes		7		5									
Medium Arc	pivot e			2										
	pivot s			3										
	pivot w			1										
	pivot es			4	2									
	pivot we		1	2	7									
	pivot ws													
	pivot wes		1		6									
Short Arc	p-rev s			2				2						
	p-rev w			3										
	pivot e		2	17	2									
	pivot s	1	1	2										
	pivot w		2	4	3									
	pivot es		1	3	2									
	pivot we			8	3									
	pivot ws													
	pivot wes			2	1									
	pivot q			1										

Table 10. Continued.

Motion form		Motion meaning												
Trajectory	Joint motion[b]	Change location in path		Reposition to reorient	Reposition to affect object	Move back/forth	Move in circle	Rotate	Open/close	Expand/contract	Bend	Wiggle	Hold	Exist
		No endpoint	Endpoint											
Arc	pivot e		1	4		19								
To/Fro	pivot s					6								
	pivot w					9								
	pivot es					21								
	pivot we			2	1	31								
	pivot ws					2								
	pivot wes				1	24								
	pivot q					2								
Circle	f-rev e						1							
	f-rev es						5	1						
	f-rev we						1	1						
	f-rev wes						2							
Revolve	finger rev							15						
	rotate							9						
Open/close[c]	finger c								2					
	finger oc								5					
	hand c								3					
	hand o								1	1				
	hand oc								1	3				
Bend	hand bend										5			
Wiggle	finger wig											3		
No motion	no change												55	28
	bounce												3	6

[a] The numbers in the table represent the total number of motion forms used for the particular meaning (i.e., tokens).

[b] The following abbreviations are used for the joint motions: e = elbow pivot; s = shoulder pivot; w = wrist pivot; q = unclear which joint was pivoted; p-rev = partial revolve of a joint; f-rev = full revolve of a joint; finger rev = fingers revolve; c = hand close; o = hand open; oc = hand open and close; wig = fingers wiggle.

[c] Note that there are two different forms in the open/close category: hand open/close and finger open/close. The finger open/close form (which is associated with the meaning "open/close") is a subset of the hand open/close form (which is associated with the meaning "expand/contract" as well as the meaning "open/close").

Table 11
David's grouped motion forms displayed in relation to motion meaning categories[a]

Motion form	Motion meaning												
	Change location in path		Reposition to reorient	Reposition to affect object	Move back/forth	Move in circle	Rotate	Open/close	Expand/contract	Bend	Wiggle	Hold	Exist
	No endpoint	Endpoint											
LinearPath	15	21	2	1	1								
LongArc	2	15	6	6									
MediumArc		2	12	15									
ShortArc	1	6	42	11			2						
ArtTo/Fro		1	6	2	114								
Circle						9	2						
Revolve							24						
Open/Close								12	4				
Bend										5			
Wiggle											3		
No Motion												58	34

[a] The numbers enclosed in the boxes represent the form–meaning pairs that met our criterion for consistent use; that is, the form–meaning pairs considered to be morphemes (see text).

Table 12
Children's motion morphemes[a]

Forms	David's meanings	Marvin's meanings	Kathy's meanings	Abe's meanings
Linear Path	Change location by moving in a path with or without an endpoint e.g., glide-forward 12(36)	Change location by moving in a path with or without an endpoint e.g., go-forward 10(17)	Reposition to affect an object e.g., reposition-to-pet 3(5)	Change location by moving in a path with or without an endpoint e.g., go 2(21)
Long Arc	Change location by moving in a path with an endpoint e.g., scoop-to-mouth 8(15)	Change location by moving in a path with an endpoint e.g., throw-to-person 5(21)	Change location by moving in a path with an endpoint e.g., fly 6(10)	Change location by moving in a path with an endpoint e.g., transfer 6(17)
Medium Arc or Short Arc	1. Reposition to reorient e.g., fall-together 23(54) 2. Reposition to affect an object e.g., reposition-to-hit 5(26)	Reposition to reorient e.g., fall-over 18(49)	1. Reposition to reorient e.g., don 14(39) 2. Change location by moving in a path with an endpoint e.g., slide-to-ground 6(23)	Reposition to reorient e.g., pull-out 21(85)
Medium Arc				Reposition to affect an object e.g., reposition-to-pat 2(9)
Short Arc		Reposition to affect an object e.g., reposition-to-press 6(7)		
Arc to & Fro	Reposition by moving back and forth e.g., flap 23(114)	Reposition by moving back and forth e.g., rock 13(30)	Reposition by moving back and forth e.g., brush 13(19)	Reposition by moving back and forth e.g., shake 11(15)

Table 12. Continued

Forms	David's meanings		Marvin's meanings		Kathy's meanings		Abe's meanings	
Circle	Reposition by moving in a circle e.g., sew-in-circle	4(9)	Reposition by moving in a circle e.g., go-in-circle	1(8)	Reposition by moving in a circle e.g., go-around	5(8)	Reposition by moving in a circle e.g., go-in-circle	1(4)
Circle or Revolve			Rotate around an axis e.g., twist	3(28)			Rotate around an axis e.g., twist	4(19)
Revolve	Rotate around an axis e.g., twist	4(24)			Rotate around an axis e.g., turn-around	2(32)		
Open & Close[b]	Open/close; expand/contract e.g., squeeze	8(16)	Open/close; expand/contract e.g., enlarge	8(28)	Open/close e.g., claw	7(15)	Open/close; expand/contract e.g., hand-close	6(18)
Bend	Bend at joint e.g., bend-in-half	2(5)	Bend at joint e.g., bend	1(1)				
Wiggle	Wiggle back and forth e.g., flutter	2(3)			Wiggle back and forth e.g., finger-wiggle	1(1)	Wiggle back and forth e.g., finger-wiggle	1(1)
No Motion	Hold or exist in place e.g., wand-hold	11(92)	Hold or exist in place e.g., cup-hold	7(65)	Hold or exist in place e.g., vacuum-hold	11(26)	Hold or exist in place e.g., gun-hold	11(66)
Proportion of gestures fitting the system	.90 ($N = 439$)		.75 ($N = 337$)		.74 ($N = 239$)		.72 ($N = 352$)	

[a] The first number in each entry represents the number of different types of actions for which the motion form was used, and the number in parentheses represents the total number of times the motion form was used for that meaning.

[b] David, Marvin, and Kathy used two different Open/Close forms: Hand Open/Close and Finger Open/Close. For all three children, the Finger Open/Close form was associated only with the meaning "open/close". Thus, for David and Marvin, the Hand Open/Close form (which meant "expand/contract" as well as "open/close") subsumes the Finger Open/Close form.

the movement involved in beating a snare drum has aspects in common with the movement involved in brushing one's teeth (both involve motion back and forth), the two movements do look different. Not surprisingly, the gestures the children create to convey these two movements, while both containing a back and forth component, also look different – the beating gesture is oriented vertically and is produced in neutral space near the chest or near (but not on) an actual drum, while the brushing gesture is oriented horizontally and is produced near the the body, in particular, the mouth. Our assumption up to this point has been that the orientation of the movement (vertical vs. horizontal) and the placement of the movement (neutral space vs. near an object vs. on the body) are separable dimensions, each of which can be "added" onto the the motion morpheme that these two gestures have in common (much as orientation and position morphemes can be added on to the root morpheme to augment motion meaning in ASL; cf. Supalla, 1982; Newport, 1990). In previous work, we have shown that one of these variations in form – placement of the movement – does indeed function as a meaningful component in the deaf child's gesture system, serving as an inflectional marker on the verb (Goldin-Meadow, Butcher, Mylander & Dodge, 1994). In this section, we test the assumption of independence for the second variation, that is, for orientation of the movement.

To test this assumption, we first need to show that orientation forms and orientation meanings can be coded, and that there is a systematic relationship between those forms and meanings. We therefore recoded all of the motions that David produced, this time transcribing orientation. We coded *form* in terms of plane of movement, and found that David used four different general orientations: he moved his gestures (1) up, down, or (in bidirectional gestures) up and down; (2) to the body, from the body, or (in bidirectional gestures) to and from the body; (3) to the right, to the left, or (in bidirectional gestures) to the right and left; and (4) across two planes in a single direction or (for bidirectional gestures) back and forth across the planes.

We assessed the *meaning* of each gesture in terms of the plane on which the motion conveyed by the gesture ought to be performed (a determination made from context). For example, if the child were describing Santa Claus' plunge down the chimney, a gesture for Santa's movements ought to depict motion in the vertical plane; such a gesture would therefore be assigned the meaning "vertical plane". We used three categories in assigning meaning: (1) vertical plane; (2) horizontal plane; and (3) diagonal plane.[13]

[13] For unidirectional motions, we also assigned the gesture a direction. For example, the gesture described in the text depicting Santa's movements would be assigned the direction "down". Not surprisingly, 90% of the 71 times David conveyed a downward direction, he moved his motion form down, and 74% of the 27 times David conveyed an upward direction, he moved his motion form up. Although it was relatively easy to assign meanings to directions

To determine whether there were consistent mappings between orientation forms and meanings in David's gestures, we again created a form-by-meaning grid, with forms along the left side of the grid and meanings across the top (see Table 13). The numbers enclosed in boxes in the table represent the consistent pairings of forms and meanings, that is the orientation morphemes. We used the same procedure to identify form–meaning pairings for orientation as was used for the other morphemes.[14] As can be seen in Table 13, David did use particular forms when conveying particular orientations. He used the up/down orientation to convey motions in the vertical plane, the right/left orientation or the to/from body orientation to convey motions in the horizontal plane, and the to/from body orientation or the cross planes orientation to convey motions in the diagonal plane; 91% of the 284 gestures David produced fit this pattern.

Thus far we have found that David used particular forms to convey particular orientation meanings and, in this sense, had a set (albeit a limited one) of orientation morphemes. However, it is still possible for orientation to be conflated with motion in David's system. We would be less likely to believe that orientation and motion formed a single, undifferentiated unit in David's gestures if, in fact, David's orientation morphemes varied freely

Table 13
David's orientation forms displayed in relation to orientation meanings

Orientation forms	Orientation meanings		
	Vertical plane	Horizontal plane	Diagonal plane
Up/down	148	2	4
Right/left	4	60	1
To/from body	2	28	12
Cross planes	4	9	10

[a] The numbers represent the total number of gestures with a particular form used for a particular meaning (i.e., tokens).

for movements in the vertical plane, it was more difficult to do so for movements in the horizontal plane. Unless the child were describing an activity in the room, it was impossible to tell whether a horizontal motion ought to be performed to the right, to the left, toward the body, or away from the body (e.g., if the child were describing a car's path of motion not a particular car but a car in general – the path could be performed in any direction). Since most of David's horizontal motions could not be assigned a particular direction, it was impossible to analyze the relationship between form and meaning with respect to direction in the horizontal plane.

[14] Because the orientation forms and meanings were not particularly variable, we used the more stringent criterion (i.e., the criterion used for the OBJECT morphemes) to determine consistent form–meaning pairings.

with his motion morphemes. If so, orientation would appear to be an independent unit – one which could be combined with any motion morpheme.

Table 14 presents the data which speak to this issue. The left side of the table lists the four motion *forms* for which orientation is relevant, each subcategorized according to the orientation in which it was produced (i.e., its orientation form). Across the top of the table are listed the five motion *meanings*, also subcategorized but according to the orientation meaning with which it occurred. To simplify the table, and because David produced relatively few cross plane forms and few diagonal meanings, we included only the up/down form and the to/from body and right/left forms (combined since they comprised a single horizontal morpheme in David's gestures, cf. Table 13), and only the vertical meaning and the horizontal meaning in the table. The numbers in the table represent the total number of gestures with a particular form (i.e, a particular orientation form and motion form) used for a particular meaning (i.e., a particular orientation meaning and motion meaning).

Not surprisingly since we have already shown that David's motion forms and meanings are consistently paired, the numbers in the table tend to fall within the boxes which demarcate David's motion morphemes. Note that, as we would expect if orientation and motion were freely varying independent morphemes in David's gesture system, all of the motion morphemes were produced in both a horizontal orientation and a vertical orientation (i.e., the upper left corner and the lower right corner of each box tend to be filled, and these cells have the largest number of instances). These findings, while not conclusive, suggest that orientation is a morpheme separable from the motion morpheme in the deaf child's gesture system.

3.8. Combinations of handshape and motion morphemes

Up to this point, we have shown that each of the four children's gestures can be described in terms of a set of handshape morphemes (i.e., handshape form–meaning pairings) and a set of motion morphemes (i.e., motion form–meaning pairings). Although isolable as separable units from the experimenter's point of view, it is still possible that handshape and motion form a single, unanalyzed whole from the child's point of view. Since gestures are composed of hands moving in space, it is not possible to find handshapes that are actually separated from their motions. Nevertheless, if we find that a handshape is not uniquely associated with one motion but rather is combined with several different motions in different gestures, we then have evidence that the handshape morpheme may be an independent unit in the child's gesture system. Similarly, if a motion is combined with different handshapes in different gestures, we infer evidence for the separability of that motion morpheme.

We first determined how many of the handshape morphemes each child

Table 14
David's motion and orientation forms displayed in relation to motion and orientation meanings[a]

Motion form		Motion meaning									
Trajectory	Orientation	Change location in path no endpoint		Change location in path with endpoint		Reposition to reorient		Reposition to affect an object		Reposition by moving back/forth	
		Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz
Linear Path	Up/down	**1**		**14**		1					
	To/from body, right/left		**7**		**3**		1		1		
Long Arc	Up/down			**2**		3		5			
	To/from body, right/left				**10**		2		1		
Medium or	Up/down			4		**30**	1	**8**	1		
Short Arc	To/from body, right/left		1		1	2	**7**	1	**15**		
Arc To & Fro	Up/down					2				**71**	
	To/from body, right/left				1		2		1	2	**34**

[a]The numbers represent the total number of gestures with a particular form used for a particular meaning (i.e., tokens); Vert = vertical; Horiz = horizontal.

produced were used with more than one motion morpheme. To do so, we excluded the handshapes that were used for only one type of object (e.g., David and Abe both used the L-shaped form for guns and no other object, cf. Tables 6 and 8) on the grounds that these forms were not productive to begin with. We then determined how many of the remaining handshapes were produced in combination with at least two motions. Of the 16 different handshape morphemes that David used, 15 were used with more than one motion morpheme and, in this sense, were productive and independent units. Similarly, 11 of the 14 handshape morphemes Marvin used, 12 of the 17 handshape morphemes Kathy used, and 11 of the 12 handshape morphemes Abe used were produced with more than one motion.

We then determined how many of the motion morphemes each child produced were used with more than one handshape morpheme (again excluding the motions that were used for a single type of motion, cf. Table 12). Of the 11 motion morphemes that David used, all were used with more than one handshape morpheme; similarly, eight of the eight motion morphemes Marvin used, eight of the nine the motion morphemes Kathy used, and seven of the eight motion morphemes Abe used were produced with more than one handshape.

Thus, most of each child's handshape morphemes could be found in combination with more than one motion morpheme, and vice versa. As a result, the children's gestures can be said to conform to a framework or system of contrasts. As an example from David's HAND morphemes of how the morphemes contrasted with one another, the CLarge handshape was used in combination with the revolve motion to mean "rotate an object 2–5 inches wide around its axis" (e.g., twist the lid of a bubble jar). The same revolve motion when used in combination with a different handshape (the OTouch) meant "rotate an object 0–2 inches wide around its axis" (e.g., twist a key). In contrast, the same OTouch handshape when combined with a different motion (the Short Arc) meant "reposition an object 0–2 inches wide" (e.g., hook-on the wire of a Christmas tree decoration).

As a similar example from David's OBJECT morphemes, the CCurved handshape was combined with the linear Path motion to mean "a curved object changes location" (e.g., a toy turtle moves forward). This same linear path motion when combined with a different handshape, a PalmStraight or Angled, meant an "animate object changes location" (e.g., David goes down). In contrast, the same handshape when combined with a different motion, a Short Arc, meant "an animate object repositions itself" (e.g., sister sits). The handshape morphemes in each child's gestures thus formed a matrix or paradigm of contrasts with the motion morphemes in the corpus of gestures.

3.9. The development of the morphological system: from wholes to parts

We next explore the developmental steps that the child might have taken in arriving at his or her handshape/motion system of contrasts. Children acquiring conventional languages, at the very earliest stages of development, tend initially to learn words as rote wholes (MacWhinney, 1978). They then realize – relatively quickly in some languages, for example K'iche' Maya (Pye, 1992), Turkish (Aksu-Koc & Slobin, 1985) West Greenlandic (Fortescue & Olsen, 1992), and more slowly in other languages, for example English (Bowerman, 1982), ASL (Newport, 1984) – that those wholes are composed of meaningful parts and they begin to use those parts as productive morphemes. Since the deaf children in our study are not learning their gestures from adult models, they might be expected to use the sub-gesture hand and motion components that we have just described productively even at the earliest stages of development. If so, we would then conclude that children begin by learning words as wholes rather than as combinations of parts *only when* they learn their words from a conventional language model.

On the other hand, it is possible that, even without a conventional language model, the child's first representation of an event is not in terms of parts, but rather in terms of the event as a whole. If so, the deaf child's first lexical items would not be composed of component parts but would instead be unanalyzed wholes which map (as wholes) onto an event. For example, the gesture *OTouch + Revolve*, if used in the context of twisting a small key and for no other objects or actions, may early in development function as an unanalyzed label for key-twisting. Later, perhaps when the child has accumulated a sufficient number of gestures in the lexicon, the child may begin to consider his or her gestures in relation to one another and may organize the gestures around any (haphazard) regularities that appear in the lexicon (i.e., the child may treat his or her own gestures as a "problem space" that needs systematization, cf. Karmiloff-Smith, 1979). For example, the child may over time accumulate a number of gestures that turn out to resemble one another: an *OTouch* + Short Arc combination used exclusively for hat-putting-on; a CLarge + *Revolve* combination used exclusively for jar-twisting. At this point, the child may notice that the *OTouch* handshape recurs across his or her gestures, and that the *Revolve* motion also recurs across those gestures. These recurring forms may then be separated from the wholes and treated as component parts. The transition then is from a state in which the child considers a gesture only in relation to the situation conveyed (a gesture–world relationship), to a state in which the child begins to consider gestures in relation to other gestures in the system (a gesture–gesture relationship).

If this second alternative is correct, we would expect that early on each gesture in a child's repertoire might be used for a single object and action rather than a variety of objects and actions. For example, a child might use a Fist + Arc To & Fro combination only in relation to drumstick-beating, and a Fist + No Motion combination only in relation to bubble-wand-blowing. After initially generating each gesture to map onto an event as a whole, the child might later "analyze" his or her set of wholes into handshape and motion components which map onto a variety of objects and actions, respectively. We would then expect that the Fist + Arc To & Fro combination, for example, would not be used only for "drumstick-beat" but for "toothbrush-brush" or "handlebars-jiggle";[15] that is, the Fist handshape in this and in other gestures would be used in relation to a variety of related objects (drumsticks, toothbrushes, handlebars – all of which are narrow and long) and the Arc to & Fro motion in this and in other gestures would be used in relation to a variety of related actions (beating, brushing, jiggling – all of which involve repositioning by moving back and forth). If the deaf children were to follow this developmental path, we would expect that a particular handshape/motion combination might be used exclusively for a single object and action in the children's early sessions but, in the later sessions, that same combination would be used for a variety of related objects and a variety of related actions.

Table 15 presents the number of different types of handshape/motion combinations each child used in relation to a single object and action versus a variety of objects and actions in each session. Note that David, Kathy, and

Table 15
Children's use of gestures in relation to a single object and action versus a variety of objects and actions[a]

	Number of types of handshape/motion combinations used for a single object and action versus a variety of objects and actions							
	David		Marvin		Kathy		Abe	
Session	Single object and action	Variety of objects and actions	Single object and action	Variety of objects and actions	Single object and action	Variety of objects and actions	Single object and action	Variety of objects and actions
I	9	1	7	0	8	1	5	3
II	7	1	9	0	6	1	11	3
III	2	0	3	2	10	1	13	1
IV	12	2	20	3	4	0	6	0
V	11	4	5	7	13	5	18	6
VI	34	12	17	9	15	5	19	7
VII	20	8	18	4	15	1	11	3

[a] The numbers at each session represent the total number of different types of handshape/motion combinations each child used during that session, classified according to whether each combination was used for a single object and action versus a variety of related objects and a variety of related actions.

[15] Although we have in this section described the meaning of each gesture in its verb form, the gesture can also be used as a noun. Whether a gesture is used as a noun or a verb – for example, whether the gesture is used to mean "to drumstick-beat" or "a beatable-drumstick" is determined by the discourse context in which it is used, with particular aspects of form varying accordingly (cf. Goldin-Meadow, Butcher, Mylander, & Dodge, 1994). It is worth noting that David (on whom extensive analyses of nouns and verbs were done; see Goldin-Meadow, Butcher, Mylander, & Dodge, 1994) did not use both a noun and a verb form of a characterizing gesture at his earliest observation sessions. Moreover, he did not begin to distinguish the form of a noun gesture from the form of a verb gesture until session IV, when he also began to use his gestures for varieties of objects and actions (cf. Table 15).

Marvin each used at least seven different types of handshape/motion combinations during the first session. However, all but one of those combinations were each used to describe only one object and action; for example, David used the Fist + No Motion combination exclusively for bubble-wand-holding. It was not until session IV that David used this same combination for a variety of objects (e.g., bubble-wand-holding, hat-brim-holding). The number of different handshape/motion combinations used for a variety of objects and actions (as opposed to a single object and action) increased over the sessions for David, Kathy and Marvin.[16]

In contrast to these three children, Abe used a relatively large number of handshape/motion combinations for a variety of objects and actions from the first of his observation sessions (cf. Table 15). The pattern for Abe suggests that we may not have caught him early enough to observe the first steps he took in fashioning a morphological system – or that Abe may have begun his gesture system, not with representations of events as wholes, but with representations of parts of events.

In sum, three of the four children appeared first to create each gesture to map, as a whole, onto an event. Only later did the children appear to "analyze" their set of wholes into handshape and motion components which mapped onto a variety of related objects and a variety of related actions, respectively.[17] The developmental pattern seen in Table 15 is consistent with the hypothesis that the children's gestures were initially unanalyzed wholes that were later organized in relation to one another to form a system of

[16] It is important to note that the onset of handshape/motion combinations used for a variety of objects and actions (as opposed to a single object and action) could not be attributed to a general increase in the total number of gestures these children produced over time. For example, Kathy produced 27 gestures in session I, when she produced only one combination for a variety of objects and actions, and 27 gestures in session V, when she produced five combinations used for a variety of objects and actions. Similarly, David produced 26 gestures in session I, when he produced only one combination used for a variety of objects and actions, and 27 gestures in session IV, when he first began to produce a larger number of combinations used for a variety of objects and actions. Indeed, for each child, the number of combinations used for a variety of objects and actions as a proportion of the total number of gestures the child produced was greater in the later sessions (V, VI, VII) than in the earlier sessions (I, II, III): the proportion increased from .04 ($N = 51$) during the early sessions to .10 ($N = 248$) during the late sessions for David, from .05 ($N = 57$) to .14 ($N = 78$) for Kathy, and from .00 ($N = 31$) to .15 ($N = 136$) for Marvin. In other words, each of these three children showed a proportional increase in his or her use of gestures in relation to a variety of objects and actions. Even for Abe, the proportion increased from .09 ($N = 75$) in his early sessions (I, II, and III) to .15 ($N = 109$) in his later sessions (V, VI, and VII), despite the fact that his use of gestures for a variety of objects and actions was already relatively high when we first observed him.

[17] In an earlier section, we argued that orientation is a third morpheme in the deaf child's system. In this regard, it is important to note that the developmental pattern seen in Table 15, which is based on the handshape and motion morphemes, does *not* change when we add the orientation morpheme. In particular, David begins to show an increase in the number of gestures used for a variety of objects and actions in session IV (age 3;3) whether or not gestures are described in terms of the two morphemes (handshape and motion), or in terms of all three morphemes (handshape, motion, and orientation).

contrasts. The data further suggest that a child's initial inclination to use gestures (or words, in the case of a hearing child learning a spoken language) as unanalyzed wholes is *not* purely an outgrowth of learning language from an adult model.

3.10. Early gestures set the stage for the morphological system

There is also evidence that the first holistic gestures that David, Kathy, and Marvin created set the stage for the system each child eventually generated. For example, in session I, David used the OTouch + No Motion combination to describe holding a bubble wand, a narrow *long* object, at his mouth. In addition, he also used the OTouch + Circular combination to describe twisting a small key on a wind-up toy, a narrow *short* object. If these examples are representative of the gestures David used at the time, he would infer that the OTouch handshape is used for objects that have relatively narrow diameters but that can be either long (like the wand) or short (like the key). Thus, on the basis of *his own* gestures, David would infer a form/meaning pairing in which the OTouch form is associated with the meaning "handle an object 0–2 inches in width and any length" (cf. Table 6).

In contrast, the first time David used the Fist handshape, he did so in session II when he used it combined with No Motion to describe holding a bubble wand at the mouth; that is, the Fist + No Motion combination was used for the same event as the OTouch + No Motion combination. However, the Fist was *not* used to describe any other objects during the early sessions. On the basis of these gestures, David would infer that the Fist handshape is used for objects that have narrow diameters and *long* lengths. In fact, when he began to consistently use gestures in relation to a variety of objects and actions in session IV, David used the Fist with the Arc To & Fro and the Short Arc motions to describe a set of objects, all having narrow diameters (0–2 inches) and long lengths (>3 inches); for example, the handle of a hammer, the handlebars of a bike, a newspaper, and the brim of a hat – precisely the range of objects eventually seen for this form in his HAND morphemes (cf. Table 6).

The first gestures each child created appeared to set the stage for the similarities and differences in handshape morphemes found across the children in Table 6. Kathy's first Fist and OTouch gestures resembled David's, and the HAND morphemes she eventually developed for these forms were also the same as David's. In session II, Kathy used the OTouch form in three gestures: (1) combined with a Circular motion to describe twisting off a narrow bubble jar lid (a narrow, short object); (2) combined with a No Motion morpheme to describe holding a straw (a narrow, long object) at the mouth; (3) combined with a Short Arc to describe pulling off cellophane wrapping (a narrow, long object). If these examples are representative of the gestures Kathy used at the time, she would infer that the

OTouch handshape is used for objects that have narrow diameters (0–2 inches) but that can either be short (like the lid) or long (like the straw and the cellophane wrapping). In other words, she would infer an OTouch morpheme comparable to David's (cf. Table 6). In addition, like David, in session I she used the Fist handshape combined with an Arc To & Fro motion to describe beating with a drumstick (a narrow, long object); she used the Fist in no other gestures in the early sessions. On the basis of these gestures, Kathy would infer that the Fist handshape is used for objects that have narrow diameters (0–2 inches) and long lengths (>3 inches) – a morpheme again comparable to David's (cf. Table 6).

In contrast, Marvin produced a different set of early gestures and developed a different set of HAND morphemes from both David and Kathy. He used the OTouch handshape as did David and Kathy – in gestures describing twisting a narrow bubble jar lid, squeezing a plastic bulb, and eating a piece of candy (i.e., handling a narrow, short object), as well as in gestures describing squeezing a plastic bubble jar (i.e., handling a narrow, long object). However, unlike David and Kathy, Marvin used his Fist handshape in the same way that he used his OTouch handshape, combined with an Open & Close motion to describe catching a bubble (a narrow, short object) and combined with a No Motion morpheme to describe holding a bubble wand (a narrow, long object) at the mouth. Thus, on the basis of the gestures he produced, Marvin would infer that there is no difference between the OTouch and the Fist forms, and both are associated with the meaning "handle a narrow object (0–2 inches) of any length" (cf. Table 6).

In sum, the patterns seen in the children's HAND morphemes in Table 6 – the similarities among the children, as well as the subtle but consistent differences – appear to have been established very early. Before each child began consistently to use a handshape/motion combination in relation to a variety of objects and actions, the child had already used the handshape in different gestures in relation to precisely the range of objects 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. Just as children provided with a conventional language model induce rules and categories from the input they receive, the deaf children in this study 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.

4. Discussion

4.1. Combinatorial structure as a resilient property of language

We have shown that deaf children, without the benefit of exposure to an accessible conventional language model, can develop gesture systems which have combinatorial structure not only at the sentence level but also at the word level. When forced by circumstances to fashion a communication system, a child can invent a system characterized by combinations at two different levels: combinations of morphemes into gestures, and combinations of gestures into sentences. Thus, our findings suggest that combinatorial structure at both sentence and word levels need not be learned from a conventional language model.

We began our descriptions of morphological structure in the deaf children's gesture systems using our own intuitions about the forms and meanings of the children's gestures, in conjunction with the framework established for morphological analyses by research on ASL. We found that this framework worked well to describe the deaf children's gestures, suggesting that the deaf children's idiosyncratic gestures can be analyzed with the same tools used to analyze conventional systems in the manual modality. It is important to point out, however, that the systems of subgesture components developed by the deaf children in our study are not as complex as the morphological system underlying ASL – a language with a rich linguistic history and shared by a wide community of signers. For example, ASL makes use of many more handshape and motion forms than the limited set described for the deaf children in our study (cf. Klima & Bellugi, 1979; Wilbur, 1987). The particular *forms* found in the deaf children's gestures may, in fact, be basic forms (basic not just to communication but to other cognitive processes as well; cf. Klatzky, McCloskey, Doherty, Pellegrino, & Smith, 1987) and as such would be expected to appear in any manual communication system – spontaneous or conventional. Moreover, even when the deaf children used the same forms as are found in ASL, the *meanings* attached to these forms often differed in the deaf children's gesture systems. For example, several of the deaf children in our study used the Linear Path to represent change of location along an unspecified path; in ASL, the linear form means move along a straight path (see also Singleton, Morford, & Goldin-Meadow, 1993, who compare the meanings for David's OBJECT handshapes to the ASL meanings for the same forms, and show systematic differences between the two systems).

Thus, the gesture systems of the deaf children in our study appear to contain a subset of the handshape and motion components found in ASL. The similarities between sign forms in ASL and gesture forms in our subjects' gesture systems suggest that our subjects' set may reflect the units that are "natural" to a language in the manual modality – units that may form part of the basic framework not only for ASL morphology but also for the morphologies of other sign languages. An examination of the early stages of acquisition of sign languages other than ASL might shed light on this issue (cf. Petitto, 1988, 1992), as would observations of spontaneous gesture systems developed by deaf children without access to a conventional sign language in other cultures. Whatever the details of the gesture systems, the fact that the gesture systems of all of the deaf children in our study could be characterized as having a morphological structure suggests that such structure is essential to the young communicator – so essential that it will evolve even in the absence of conventional linguistic input.

4.2. Arbitrariness as a resilient property of language

The form of morphemes in spoken languages is arbitrary. As Saussure (1916/1959) observed, the sequences of sounds in "sister" or "soeur" or "hermana" (are not transparently related to the concept "sister", which each of these sound sequences represents. Rather, each sound sequence is associated with this particular meaning by the conventions established in the English-, French-, and Spanish-speaking communities, respectively. Arbitrariness is so salient in language that Hockett (1977) included it within his list of design features said to distinguish human communication systems from animal communication systems.

We do not want to argue that the gesture systems of the deaf children in this study were arbitrary in the Saussurian sense. Indeed, the absence of shared conventions and the impetus of the child to communicate clearly limited the potential for idiosyncrasy in the deaf child's gesture system. In fact, the study of "how limited" was a major thrust of these investigations. To this end, it is worth noting that the children did introduce arbitrary distinctions into their gesture systems; that is, not all of the children's systems were identical. The fact that there were differences in the way the children defined a particular morpheme suggests that there were, in fact, choices to be made. Moreover, the choices that a given child made could not be determined without knowing that child's individual system. In other words, one cannot predict the precise boundaries of a child's morphemes without knowing that child's individual system. It is in this sense that the deaf children's gesture systems can be said to be arbitrary.

In addition to suggesting that they were able to introduce arbitrariness into their gesture systems, the differences across the deaf children's systems suggest that the children had different standards of well-formedness within their individual systems. The children's gestures not only were adequate representations of objects and movements in the world, but they also conformed to an internally consistent system and, in this sense, each system had standards of form. Further evidence that the deaf child's gesture system is characterized by standards of form comes from the fact that, in an experimental test of his morphological system conducted when he was 9;5, David, one of the deaf children in this study, spontaneously corrected some of his hearing sister's gestures which did not conform to his gestural system (the sister used a handshape to convey a meaning that had to be conveyed by a different handshape in David's system; Singleton et al., 1993). Although it is not necessary for a language-user to correct another's "mispronunciation" in order to suggest that the user adheres to standards of form (such corrections imply a certain level of consciousness which a user need not have), corrections of another's performance can provide further evidence of a standard. Thus, David appeared to have a well-developed and articulated sense of what counts as an acceptable gesture, and he was not shy about informing others of his standards. In addition, in an analysis of the spontaneous gestures that David used over a 2-year period, Goldin-Meadow, Butcher, Mylander, and Dodge (1994) found that the child tended to use precisely the same gestural form for the same meaning throughout this relatively long period; that is, he appeared to have a stable lexicon of gestures at his disposal. Taken together, these findings suggest that, even without a conventional language model, children are able to introduce relatively arbitrary standards of form into their communication systems (although such standardization may require a period of time, perhaps years, to evolve; cf. Singleton et al., 1993).

Note that, although the distinctions the children introduced into their systems differed from one another in apparently idiosyncratic ways, these distinctions did little to decrease the overall iconicity of the children's gesture systems. Indeed, what is most striking about the children's gesture systems is the iconicity of each system, and the similarities across the systems that come about presumably because each system leans toward iconicity. Such iconicity is, in fact, not surprising given that the deaf children's gesture systems must be relatively transparent in order to be understood by the hearing individuals who communicate with the children. As described above, the deaf children's families had chosen to educate them through an oral method, and their emphasis was on their children's (minimal) verbal abilities. The families did not treat the children's gesture as though it were a language. In other words, they were not partners in the gestural communication that the children used. Thus, in order to be understood, the deaf children's gestures needed to be iconic, that is, transparently related to their referents. An interesting question to pose is how far a deaf child can move toward arbitrariness without a conventional language as a model, but with a willing communication partner who could enter into and share an arbitrary system with the child. To date, the circumstances that would allow us to address this question – two deaf children inventing a gestural system with no input from a conventional sign language – have not been described (but see Kegl, 1994; Senghas, 1994).

Because of the unusual circumstances in which they find themselves, the deaf children must at least begin by inventing gestures that are iconic. Moreover, their circumstances do not allow them to stray too far from iconicity if their gesture systems are to be understood. Note, however, that children who do not have to invent their language but have only to learn it appear to side-step iconicity altogether. Although sign languages are structurally comparable to spoken languages at both morphological and syntactic levels, they differ from spoken languages in having a relatively large number of lexical and morphological constructions that are iconically motivated. Linguists and psycholinguists have argued that this iconicity is, in a sense, a red herring – it plays no role in the structural descriptions of the language, nor does it play a role in the way the language is processed (Klima & Bellugi, 1979). Nevertheless, iconicity might provide a way into the formal linguistic system that could be exploited by the young language-learning child. However, in a longitudinal study of spontaneous signing (1981) and in a cross-sectional study in an experimental setting (1987), Meier has shown that the iconicity available in sign language is *not* exploited by the language-learning child; that is, iconic signs were not learned any more easily than non-iconic signs (see also Petitto, 1988). These findings suggest that children will approach language as a formal system even if there is an apparently easier, iconic route open to them. Children appear to exploit iconicity only when it is necessary to do so, as in the circumstances in which the deaf children in our study find themselves.

Thus, the similarities across the deaf children's gesture systems are easy to explain. They appear to be an outgrowth of the need for each system to be understood by non-users and, as a result, to be iconic. However, it is more difficult to explain the arbitrary distinctions evident in each of the systems. We have speculated that it is the early gestures that the children create which pave the way for the distinctions each child eventually makes. For example, in their initial observation sessions, both David and Kathy created gestures with an OTouch handshape; some of these gestures were used to describe bubble wands and straws (narrow, long objects) and some were used to describe jar lids and short keys (narrow, short objects). In contrast, the gestures with a Fist handshape that both children created were used to describe bubble wands, straws, and toothbrushes (i.e., only narrow, long objects). Over a year later the children's gesture systems still showed this pattern (i.e., the OTouch was used to describe narrow objects of any length, and the Fist was used to describe narrow, long objects). Marvin's early gestures showed a different pattern from David's and Kathy's, and that pattern too was evident 1 year later in the handshape morphemes Marvin used.

We have further speculated that the process by which such distinctions come about involves a developmental step in which the child begins to survey his or her set of gestures and to consider those gestures as a "problem space" in need of systematization (cf. Karmiloff-Smith, 1979). This process is, in fact, comparable to the process deaf children of deaf parents use when they acquire the signs of ASL. When first generating gestures, the deaf children in our study seemed to have created each gesture to map onto a single action and object, focusing primarily on the relationship between the gesture and events in the world. This stage is reminiscent of the period during which deaf children acquiring ASL treat their morphologically complex signs as unanalyzed wholes (Newport, 1984). Later in development, the children in our study began to use a single gesture in relation to a variety of actions sharing a common attribute (reflected in the motion component of the gesture) and a variety of objects sharing a common attribute (reflected in the handshape component of the gesture; cf.

Table 15). At this point, then, the children's gesture systems can be described in terms of components of gesture forms mapping onto components of gesture meanings, rather than the whole gesture form mapping onto a global, particular event. The focus now is on the relationship between the gesture and other gestures in the system (i.e., gesture–gesture links), rather than exclusively on the relationship between the gesture and events in the world (i.e., gesture–world links). This latter stage is comparable to the period when deaf children acquiring ASL begin to analyze the signs they have learned as wholes and separate these signs into meaningful components (Newport, 1984; see Bowerman, 1982, and MacWhinney, 1978, for descriptions of a similar developmental pattern in hearing children acquiring spoken language).

In sum, we have shown that, even without a conventional language model, deaf children can develop gesture systems characterized by morphological structure. We have furthermore suggested that the gestures the deaf children in our study created for themselves were the central forces in shaping the children's morphological systems. However, it is also possible that the spontaneous gestures produced by the hearing individuals in each child's world played a role in shaping that child's morphological system. We investigate this possibility in Study 2.

STUDY 2: PARENTAL INPUT TO THE DEAF CHILD'S MORPHOLOGICAL SYSTEM

The deaf children in Study 1 were not exposed to a conventional sign language during the time of our observations and thus did not learn their gestural systems in the traditional sense of the word. Nevertheless, the children were exposed to the spontaneous gestures their hearing parents used when speaking to them (as are hearing children of hearing parents; cf. Bekken, 1989; Shatz, 1982). These gestures could conceivably have served as input to the children's gestural systems and, therefore, must be the background against which their gestural accomplishments are evaluated.

In our previous analyses of parental input to sentence-level structure in the deaf children's gestures, we found that, although the deaf children's hearing mothers did indeed gesture, they produced relatively few gesture strings. Moreover, the few gesture strings they did produce either showed no structural regularities whatsoever, or showed a different structural pattern from the pattern found in their child's gesture strings (Goldin-Meadow & Mylander, 1983, 1984). However, the deaf children's mothers were found to produce single gestures more often than their children. In addition, a large proportion of each mother's single gestures were characterizing (mimetic) gestures rather than deictic (pointing) gestures (Goldin-Meadow & Mylander, 1984). Thus, the mothers produced a substantial number of characterizing gestures during the time when their children were developing their morphological systems, and these characterizing gestures may have served as models for those systems. The goal of Study 2 is to determine which aspects of the deaf children's morphological systems might be traced to the gestural input produced by their hearing mothers and which aspects go beyond this input.

5. Method

The hearing mothers of the four deaf children in Study 1 were the subjects for this study. We transcribed all of the characterizing gestures that each mother produced during the videotaped sessions of her child and evaluated those gestures in two separate analyses.[18] (1) In the first analysis, we coded the gestures the mothers produced within the framework of the morphological system developed by her child, and assessed how well the mother's gestures conformed to the child's morphological system. (2) In the second analysis, we coded the mothers' gestures using the same procedures that we used to code the children's gestures (see Study 1); in other words, we treated each mother's gestures as a system unto itself, and assessed how well each child's gestures conformed to his or her mother's system.

6. Results

6.1. Do the mothers' gestures conform to their children's systems?

We found that the hearing mothers of all four of the deaf children produced instances of the five major handshapes (Fist, O, C, Palm, and Point) but fewer instances of the 28 different handshape forms than their respective children produced. David's mother produced 19 of the 28 forms, compared to David's 25. The comparable numbers for the other mothers and children were (mother vs. child): Marvin 14 versus 22; Kathy 12 versus 24; Abe 15 versus 20. The hearing mothers also produced most of the motion forms that their children produced. David's mother produced 10 of the 11 motion forms, compared to David's 11. The comparable numbers for the other pairs were (mother vs. child): Marvin 9 versus 10; Kathy 10 versus 10; Abe 11 versus 10.

In terms of how the mothers used their forms to convey meanings, we found first that the mothers used significantly more TRACE handshapes

[18] As in our analyses of the children's gestures, we eliminated all of the conventional gestures each mother used (i.e., the stereotyped gestures commonly found in our culture in which gesture form was less transparently related to meaning). David's mother produced 103 conventional gestures (18% of her total 580 gestures), Marvin's mother produced 35 (10% of 356), Kathy's mother produced 16 (10% of 165), and Abe's mother produced 47 (18% of 268).

than did their children, that is, handshapes which were at right angles to the motion; these handshapes (which were frequently points) did not portray aspects of an object (and, in this sense, were meaningless), but rather functioned to trace the path of motion. Of David's mother's 233 gestures, .17 were TRACES, compared to .05 ($N = 445$) for David ($\chi^2(1) = 26.1$, $p < .001$). The comparable percentages for the other mother-child pairs were: Marvin mother .39 ($N = 157$) versus child .19 ($N = 343$; $\chi^2(1) = 21.6$, $p < .001$), Kathy mother .48 ($N = 82$)versus child .23 ($N = 244$; $\chi^2(1) = 17.5$, $p < .001$), and Abe mother .31 ($N = 80$) versus child .16 ($N = 357$; $\chi^2(1) = 9.5$, $p = .002$). Thus, for three of the four mothers, *a third to a half* of their handshapes conveyed no meaning and could not even be considered in terms of a morphological system.

To determine whether each mother used her remaining handshape forms and her motion forms to convey the same meanings as her child, we calculated the proportion of each mother's gestures that conformed to her child's system of form/meaning pairings displayed in Tables 6 and 8 (for handshape morphemes) and Table 12 (for motion morphemes). Not surprisingly, since these tables were developed on the basis of the child's gestures and not the mother's, the proportion of each mother's gestures conforming to her child's system is smaller than the proportion of the child's gestures conforming to his or her own system, for both handshape – David mother .53 ($N = 150$) versus child .92 ($N = 367$); Marvin mother .71 ($N = 79$) versus child .90 ($N = 236$); Kathy mother .79 ($N = 43$) versus child .84 ($N = 172$); Abe mother .72 ($N = 53$) versus child .81 ($N = 264$) – and motion – David mother .70 ($N = 225$) versus child .90 ($N = 439$); Marvin mother .58 ($N = 153$) versus child .75 ($N = 337$); Kathy mother .33 ($N = 76$) versus child .74 ($N = 239$); Abe mother .66 ($N = 73$) versus child .72 ($N = 352$).

More importantly, even when the mothers used gestures that conformed to their children's gesture systems, they used those gestures in a more restricted way than their children. Table 16 presents data on each mother's

Table 16
Mother's use of her child's morphemes[a]

	Handshape morphemes			Motion morphemes		
	Proportion of child's morphemes that:			Proportion of child's morphemes that:		
	Mother fails to use	Mother uses more narrowly than child	Mother uses identically to child	Mother fails to use	Mother uses more narrowly than child	Mother uses identically to child
David	.31	.31	.37	.09	.09	.82
Marvin	.50	.33	.17	.10	.30	.60
Kathy	.65	.05	.30	.40	.10	.50
Abe	.50	.10	.40	.30	.20	.50

[a] Proportions are calculated on the total number of handshape morphemes (David 19, Marvin 18, Kathy 20, and Abe 20) and the total number of motion morphemes (David 11, Marvin 10, Kathy 10, and Abe 10) that each child had in his or her system.

use of her child's morphemes. Focusing first on handshape, we see that each of the mothers failed to use a substantial proportion (.31–.65) of the handshape morphemes found in her child's gestures. Moreover, when the mothers did use their children's handshape morphemes, they frequently used them more narrowly than their children (e.g., while David used both the OTouch and the OSmall forms for objects 0–2 inches in width, his mother used only the OTouch for this meaning). In fact, only .17 to .40 of the children's handshape morphemes were used by the mothers in precisely the same ways the children used them. In terms of the motion morphemes, the mothers did a better job of using their gestures that fit the children's systems in precisely the same way as did their children, although here again Kathy's and Abe's mothers used only half of their children's motion morphemes in the same way as their children. Thus, particularly for handshape morphemes, the mothers' gestures presented only a partial model at best for the systems their children developed.

A similar picture is found when we explore the types of handshape/motion *combinations* that the mothers produced. We find that once again the mothers used a subset of the gestures that their children used. Table 17 presents the number of types of handshape/motion combinations that the mother and child produced in common, first, as a proportion of all of the different types of combinations that the child produced and, second, as a proportion of all of the different types of combinations that the mother produced. As can be seen in the table, a small proportion (from .08 to .33) of the child's combinations were also produced by the mother, while a much larger proportion (from .44 to .83) of the mother's combinations were produced by her child. Thus, in a sense, the child was a better model for the mother than the mother was for the child.

Finally, we examined the mothers' gestures over time, focusing on whether the mothers used their gestures in relation to a single object and action or a variety of objects and actions. In other words, we asked whether

Table 17
Handshape/motion combinations used by both mother and child

	Handshape/motion combinations produced by both mother and child as a proportion of **child's** combinations	Handshape/motion combinations produced by both mother and child as a proportion of **mother's** combinations
David	.33 (67)	.73 (30)[a]
Marvin	.30 (50)	.83 (18)
Kathy	.08 (48)	.44 (9)
Abe	.16 (57)	.53 (17)

[a] The numbers in parentheses are the total number of different types of handshape/motion combinations that are produced by the child and mother, respectively. Note that, for each pair, the child produced many more different types of handshape/motion combinations than did the mother.

Table 18
Mother's use of gestures in relation to a single object and action versus a variety of objects and actions[a]

Session	Number of types of handshape/motion combinations used for a single object and action versus a variety of objects and actions							
	David Mother		Marvin Mother		Kathy Mother		Abe Mother	
	Single object and action	Variety of objects and actions	Single object and action	Variety of objects and actions	Single object and action	Variety of objects and actions	Single object and action	Variety of objects and actions
I	7	1	1	0	3	0	1	1
II	8	0	7	0	2	0	1	1
III	3	0	3	2	2	1	7	1
IV	7	3	7	1	1	1	1	0
V	6	2	2	2	1	0	2	0
VI	5	0	2	1	0	0	8	0
VII	8	0	2	2	2	0	3	0

[a] The numbers at each session represent the total number of different types of handshape/motion combinations each child's mother used during that session, classified according to whether each combination was used for a single object and action versus a variety of related objects and a variety of related actions.

the mothers used their gestures primarily as holistic representations or as combinations of meaningful parts. Table 18 presents the number of different types of handshape/motion combinations each mother used in relation to a single object and action versus a variety of objects and actions in each session (and should be compared to Table 15, the comparable table for the children). Unlike the data for the children, the number of handshape/motion combinations used for a variety of objects and actions does *not* consistently increase over the sessions for any of the mothers. Indeed, the number of combinations that each mother used for a variety of objects and actions did not differ from the number her child used during the early sessions (I, II, and III) but was considerably smaller than the number her child used during the later sessions (V, VI, and VII). David's mother used one combination during the early sessions for a variety of objects and actions and he used two; however, during the later sessions, mother used only two combinations for a variety of objects and actions while David used 24. The comparable numbers for Marvin were two versus two (mother vs. child) during the early sessions and five versus 20 during the later sessions; the numbers for Kathy were one versus three (mother vs. child) during the early sessions and zero versus 11 during the later sessions. Note that Abe, who appeared to have already decomposed his gestures into handshape and motion morphemes during the initial observation session (cf. Table 15), used more handshapes in relation to a variety of objects and actions than his mother during *both* the early sessions (three versus seven, mother vs. child) and the later sessions (zero versus 16). Thus, unlike the children, the mothers continued to use each of their handshape/motion combinations as a label for a single object and action throughout the observation sessions – a strategy suggesting that the mothers treated each gesture as an unanalyzed whole.

One final point is worth noting. If the children had used their mothers' gestures as a model for their own, all of their mothers' gestures would have to have served as part of that model – including those gestures to which we were unable to assign a meaning and which have not been included in our analyses thus far. If, when calculating the proportion of mother's gestures that conformed to her child's system, we add in the ambiguous gestures that each mother produced, we find that each mother's proportion of fits decreases substantially to less than .50 for both handshape – .26 ($N = 299$) for David's mother; .31 ($N = 183$) for Marvin's mother .47 ($N = 72$) for Kathy's mother; .36 ($N = 104$) for Abe's mother – and for motion – .42 ($N = 374$) for David's mother; .35 ($N = 257$) for Marvin's mother; .24 ($N = 105$) for Kathy's mother; .39 ($N = 124$) for Abe's mother. Thus, in order for the children to have used their mothers' gestures as models for their own, they would have to have been able to extract the regularities that they eventually developed from a very noisy data base – one in which *fewer than half* of the gestures instantiated the child's system.

6.2. *Do the children's gestures conform to their mothers' systems?*

Thus far we have analyzed the mothers' gestures within the morphological frameworks established for their children, and found that each mother's gestures fit her child's system only moderately well. Moreover, mother's gestures that did fit the child's system comprised a subset of that system. In other words, each mother used her gestures in a more restricted way than her child, omitting many of the morphemes that the child produced (or using the ones she did produce more narrowly than the child), and omitting many of the handshape/motion combinations that the child produced. Thus, the mothers' gestures did not conform to the morphological systems described for the four children in Study 1. It is possible, however, that the mothers' gestures did have some impact on the children's systems. For example, we found in Study 1 a number of arbitrary distinctions that distinguished the children's systems from one another; these distinctions may have arisen in response to the different gestures each child's mother used. To explore this possibility, we reanalyzed each mother's gestures as a system unto itself, using the procedures described in Study 1 to do so. We formulated handshape and motion morphemes for each mother's gestures and compared those morphemes to the morphemes described for her child.

Not surprisingly, since the mother's gesture system was constructed to ft her gestures and not her child's, the proportion of each child's gestures that conformed to his or her mother's system was lower than the proportion that conformed to the child's own system, both for handshape – .79 conforming to mother's system versus .92 conforming to his own system for David; .46 versus .90 for Marvin; .62 versus .84 for Kathy; .67 versus .81 for Abe – and for motion – .81 versus .90 for David; .50 versus .75 for Marvin; .57 versus .74 for Kathy; .63 versus .72 for Abe.

More importantly, however, the system that fit mother's gestures was

Table 19
Proportion of forms used for the same meanings in child's and mother's systems[a]

	Handshape forms	Motion forms
David	.33 (15)	.60 (10)
Marvin	.15 (13)	.22 (9)
Kathy	.33 (9)	.33 (9)
Abe	.27 (11)	.30 (10)

[a] The forms described in this table are those used by *both* child and mother. Each of the mothers failed to use some of her child's forms in her own system: David's mother failed to use five of David's 20 handshape forms, and one of his 11 motion forms; Marvin's mother failed to use six of Marvin's 19 handshape forms, and one of his 10 motion forms; Kathy's mother failed to use 10 of Kathy's 18 handshape forms, and one of her 10 motion forms; Abe's mother failed to use seven of Abe's 18 handshape forms. In addition, Kathy failed to use one motion form that her mother used, and Abe failed to use two handshape forms that his mother used.

distinct from the system that fit her child's. The proportion of forms used for the same meanings in the child's system and in the mother's system ranged from .15 to .33 for handshapes and from .22 to .60 for motions across the four mother–child pairs (see Table 19). Thus there was very little overlap, particularly in handshapes, between the gesture systems developed by mother and child. Indeed, the arbitrary distinctions that were found across the children's systems could *not* easily be traced to distinctions in the mothers' gestures. Consider the Fist and OTouch HAND forms that we examined in detail for the children in Study 1. Recall that David distinguished these two forms; he used the Fist for objects 0–2 inches wide and >3 inches long, and the OTouch for object 0–2 inches wide but of any length. David's mother, however, used both forms for objects 0–2 inches wide (with no length restrictions); that is, she did not distinguish the two forms in her gestures. Kathy used the Fist and OTouch in the same way that David did and, although her mother did distinguish the two forms, she did so differently than her child; she used the Fist for objects 0–1 inch wide, and the OTouch for objects 0–2 inches wide. Even more strikingly, Marvin and his mother showed no overlap whatsoever. Marvin used both forms for objects 0–2 inches wide, while his mother used the Fist for objects 0–1 inch wide and the OTouch for objects 2–3 inches wide. Thus, the idiosyncratic patterns of use found in the children's gestures could not be traced to the gestures that their mothers produced.

7. Discussion

7.1. *The mismatch between mother and child: gesture with and without speech*

We found in Study 1 that the deaf children's gestures could be characterized by a productive system of handshape and motion morphemes. Could the mothers' gestures have served as models for these productive systems? In Study 2, we found that the mothers' gestures conformed to the morphological systems of their children only moderately well. Moreover, the gestures mother produced that did fit her child's system did not exhibit the full range of that system and therefore could not have served as a complete model for the system. Finally, unlike the children, the mothers did not convincingly use their gestures for varieties of objects and actions but seemed to use their gestures as holistic labels for a single object and action. Thus, the mothers' gestures did not fit their children's systems particularly well.

In addition, we found that the children's gestures did not fit their mothers' systems particularly well either. We analyzed the mothers' gestures with the same tools used to analyze the children's gestures and found that the resulting systems for the mothers did not capture the children's gestures well at all. Moreover, the differences across the children's systems found in Study 1 could not be easily traced to the mothers' systems, but seemed to be shaped by the early gestures that the children themselves created.

Thus, the mothers' gestures could not have served as complete models for the morphological systems the deaf children developed. Nevertheless, it is possible that the children used their mother's gestures as a starting-off point. We did, in fact, find some commonalities across the gestures of all of the mothers and children in certain areas; for example, mothers and children alike tended to use the Fist, the OTouch, and the OSmall handshape forms for objects with narrow diameters. Thus, the children might have made use of certain characteristics of their mothers' gestures as a basis for constructing the units of their morphological systems. However, if they did so, they themselves must have contributed a great deal of structure to the systems as well. At the least, they would have needed to refine the handshape and motion categories their mothers used (since the mothers' categories were not identical to the ones the children eventually developed), to introduce new handshape and motions categories for the forms that the mothers did not use, to introduce new handshape/motion combinations that did not appear in the mothers' gestures, and to introduce consistent use of gestures in relation to varieties of objects and actions rather than a single object and action.

Note that the gestures produced by the mothers and children in our study resembled each other more closely in terms of motion morphemes than in terms of handshape morphemes. Why might this be so? It may, in fact, be easier for movement of the hand to transparently represent motion, than for the shape of the hand to transparently represent objects (see Singleton et al., 1993, for discussion). Thus, the potential for iconicity in representing motion via gesture may explain why there was more commonality in the motions the mothers and children used than in their handshapes. In general, in spontaneous gesture, one tends to find more commonality in the motions individuals use to represent an event than in the handshapes. In a series of examples described by McNeill (1992, pp.106–108) of hearing adults gesturing as they narrated a cartoon, one can see commonality in the movements each of the speakers used but not in the handshapes. For example, when describing a scene from a cartoon in which one character tries to reach a second character by climbing up the inside of a drainpipe, four of five speakers produced the same rising motion but did so with a variety of different handshapes (e.g., index finger, first and second fingers extended, a basket-like handshape). Since the hearing mothers in our study appeared to be using the same types of gestures that hearing individuals typically use as they speak, it is not surprising that there should be less variability across the mothers in the motions they used than in their handshapes. Since there is also less variability across the deaf children, the children may have extracted their motion forms from the relatively limited set used by their hearing mothers or, alternatively, they could have generated the same limited set on their own.

7.1.1. Gesture as a primary communication system versus gesture as an adjunct to speech

We have found that the children's gestures did not really resemble their mothers' gestures, nor did the mothers' gestures resemble their children's gestures. Why was there so little in common between the gesture systems of mother and child? One might have expected that because they interact with one another on a daily basis, mother and child would develop gesture systems that resemble one another. We suggest that the hearing mothers' gestures and the deaf children's gestures were structured so differently because the hearing mothers produced gestures for a different purpose than did the deaf children (Goldin-Meadow, 1993).

The hearing mothers rarely gestured without speaking (not surprisingly, given that the mothers were committed to teaching their children spoken English). Thus, their gestures were all produced along with speech and served as an adjunct to that speech, which itself assumed the primary burden of communication. Like all speech, the mothers' words were organized into combinations according to rules of syntax and morphology. However, their gestures showed no evidence of either syntactic or morphologic structure. The deaf children's mothers were not unique in this respect – when speaking individuals gesture, they tend to produce a single gesture within each spoken clause (i.e., they do not combine their gestures into strings; cf. McNeill, 1992) and each gesture tends to serve as a holistic depiction, like a picture or an enactment, presented in a single moment of time (i.e., their gestures are not composed of smaller parts; cf. Kendon, 1993). This holistic representation is adequate for the deaf children's mothers, as it is for all speaking individuals, simply because gesture is framed by the speech it accompanies; that is, speech supplies the focus and context that allows interpretation of the accompanying gesture.

In contrast to the mothers' gestures (and those of all speaking individuals), the gestures produced by the deaf children in our study assumed the burden of a primary communication system and thus, in a sense, were required to frame themselves. To better understand this distinction, consider how holistic gesture of the type that typically accompanies speech might fare if it were produced without speech. It is possible to depict an event, for example "drinking a cup of coffee", by enacting that event (i.e., one might move a hand shaped as though holding a cup toward one's open mouth). However, given this holistic representation, how would one request someone else to have a cup of coffee, or comment on the fact that coffee-drinking is done routinely, or warn a hopeful drinker that this cup of coffee is cold? It becomes increasingly difficult to fulfill the diversity of communicative functions that language typically serves without being able to isolate certain elements of the event (e.g., the drinker, the coffee) and comment on those elements. It appears as if gesture must be both decomposable and combinatorial in order to function as a primary "linguistic" communication system.

In our previous work, we have shown that the deaf child's gestures did indeed serve as elements in gesture strings, thus forming a simple syntax (Goldin-Meadow & Mylander, 1984). In this study, we have shown that these gestures were themselves composed of recombinable elements, thus forming a simple morphology. It is precisely this type of combinatorial system that appears to be necessary for language to fulfill the range of functions it typically serves and that gives the deaf children's gesture its language-like quality.

7.1.2. Gesture and speech as an integrated system

The gestures that the hearing mothers produced were, by contrast, not language-like and, in fact, appeared to be no different from the gestures that hearing individuals typically use with speech (cf. McNeill, 1992). McNeill has shown that the spontaneous gestures that hearing individuals produce lack the segmentation, compositionality, and standards of well-formedness that are characteristic of conventional language (signed or spoken) and of our deaf children's gesture systems. Indeed, although we did impose a morphological system on the hearing mothers' gestures, it is not at all clear that such an analysis is appropriate for such gestures. For example, when applied to the mothers' gestures, our tools of analysis often resulted in categories that were quite incoherent. Marvin's mother used the CMedium form for objects which were narrower in width (1–2 inches) than the objects for which she used the OTouch form (2–3 inches) – as did Kathy's mother who used the CMedium form for objects 0–1 wide and the OTouch form for objects 0–2 inches wide. The CMedium has a greater thumb–finger distance than the OTouch; if these handshape forms were being used to systematically capture differences between objects, we would expect the CMedium to be used for wider objects than the OTouch (as it was in all four of the children's systems). As a second example, Abe's mother used the Fist handshape to represent straight-wide objects (as opposed to bulky objects, the type of object represented by the Fist in all four children). In terms of motions, David's mother used one form, the Short Arc, for three distinct meanings – change location in a path with an endpoint, reposition to reorient, and reposition to affect an object – meanings which all four of the children represented with at least two different forms. Marvin's mother represented the meaning expand/contract with the Medium Arc form rather than with the Open & Close form used by all of the children who conveyed this meaning. In addition, using our tools of analysis, many of the mothers' gestures could not be assigned a meaning: 39% of David's mother's gestures appeared meaningless when examined using our system of analysis, as were 26% of Kathy's mother's gestures, 40% of Marvin's mother's gestures, and 28% of Abe's mother's gestures. In fact, McNeill (1992) has argued that the gestures which accompany speech form an integrated system with that speech and appear systematic *only when* considered in relation to the speech. Thus, it is possible that the mothers' gestures which were uninterpretable using the tools of analysis developed to code the deaf children's gestures – primary communication systems – might have been quite meaningful if analyzed with tools developed to code gesture in relation to speech (cf. McNeill, 1992; see Goldin-Meadow, Alibali, & Church, 1993, for further evidence that gesture and speech in hearing individuals form an integrated system; and Morford & Goldin-Meadow, 1992, for evidence that such an integrated system is developed quite early in children learning conventional spoken languages).

We are, in a sense, suggesting that because the gestures of the hearing mothers in our study formed an integrated system with their speech and were constrained by that speech, those gestures were not "free" to assume the language-like qualities of their deaf children's gestures. Thus, one might suspect that if the mothers merely refrained from speaking as they gestured, their gestures might have become closer in structure to their children's gestures. In fact, in an experimental test of this prediction, Singleton, Goldin-Meadow, and McNeill (1995; see also Goldin-Meadow, McNeill, & Singleton, 1995) asked hearing individuals to depict events in a series of filmed segments using gesture and no speech. They found that, as expected, the nature of the hearing individuals' gestures changed dramatically when those gestures were forced to assume the full burden of communication. Their gestures no longer appeared global and synthetic, representing an entire proposition within a gesture, but became much more discrete and segmented, reminiscent of the deaf children's gestures. It is worth noting, however, that the hearing individuals in the Singleton et al. (1995), study appeared to generate each gesture with an eye toward how well that gesture represented a referent but with little concern for how well the gesture fit with the other gestures the individual generated. In contrast, when asked to perform the same task, David, one of the deaf children in the study reported here, generated gestures that not only represented objects and motions well but that also conformed to an internal system (indeed, the system was comparable to the system described here on the basis of David's spontaneous gestures, despite the fact that the experimental study was conducted when David was 9;5, several years later than the study described here; Singleton et al., 1993). These data suggest that although discreteness may be an immediate consequence of gesturing without speaking, developing the type of internal consistency that the deaf children in our study demonstrated (i.e., gesture-to-gesture relations as well as gesture-to-referent relations) may require a period of years in which gesture is used as a primary communication system.

7.2. Morphological structure in the absence of a conventional linguistic model

In sum, we have shown that children, even in the absence of an accessible conventional language model, can develop a communication system with combinatorial structure not only at the sentence level but also at the word level. The word-level structure that the children exhibited was, however, quite simple – far simpler than the word-level structure found in the speech or sign of children learning a conventional language. Although the children in this study were able to go well beyond the spontaneous gestures they received from their hearing mothers in fashioning a gesture system with morphological structure, their progress did seem to be constrained by that input – particularly when their gesture systems are compared to the sign system developed by a deaf child whose input was richer than the input the children in our study received yet impoverished relative to the norm. Singleton and Newport (1994) have described the morphological system developed by a deaf child who received as input from his late-learner deaf parents only the lexicon of ASL and a very degraded model of the morphological structure. Despite the degraded input he received, the child was found to have gone substantially beyond his impoverished input to develop a sign system with the complexity of ASL. Thus, having a set of lexical items from which to work appeared to allow the deaf child in Singleton and Newport's (1994) study to develop a morphological system with far more complexity than the morphological systems developed by the deaf children in our study.

In addition to being constrained by the input they received, the deaf children may have been limited by the unusual communication circumstances in which they found themselves. Their hearing parents were committed to teaching their deaf children to speak and thus focused on the children's minimal spoken vocabularies rather than their gestures. In fact, they took little notice of their own or their deaf child's gestures. As a result, if the children wanted to be understood, they could not produce gestures that were arbitrarily related to their referents but needed instead to produce gestures that were iconic.

However, despite this strong push toward iconity, one can see the beginnings of relatively arbitrary standards of form – the beginnings of what one might call conventionality – in the deaf children's gesture systems. Thus, our findings suggest that the drive to communicate using a combinatorial system of arbitrarily defined categories need not be instilled in the child via a conventional language model.

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