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Assessing Knowledge Through Gesture: Using Children's Hands to Read Their Minds

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Is the information that gesture provides about a child's understanding of a task accessible not only to experimenters who are trained in coding gesture but also to untrained observers? Twenty adults were asked to describe the reasoning of 12 different children, each videotaped responding to a Piagetian conservation task. Six of the children on the videotape produced gestures that conveyed the same information as their nonconserving spoken explanations, and 6 produced gestures that conveyed different information from their nonconserving spoken explanations. The adult observers displayed more uncertainty in their appraisals of children who produced different information in gesture and speech than in their appraisals of children who produced the same information in gesture and speech. Moreover, the adults were able to incorporate the information conveyed in the children's gestures into their own spoken appraisals of the children's reasoning. These data suggest that, even without training, adults form impressions of children's knowledge based not only on what children say with their mouths but also on what they say with their hands.

When teachers interact with a class, a small group of children, or an individual child, they continually make judgments about how much children know, how they approach a given problem, and what they are capable of learning next. Based on these judgments, a teacher will modify the way in which he or she next interacts with or attempts to teach the student.

Verbal feedback from children is one prominent source of information that may help the teacher assess a child's knowledge of a problem. However, children often have difficulty monitoring and assessing accurately their own state of understanding (Brown & DeLoache, 1978; Flavell, Speer, Green, & August, 1981; Markman, 1977, 1979) and, as a result, may send false or uninformative verbal messages to their teachers or listeners (Flavell, 1981; Markman, 1979).

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A second potential source of feedback for teachers and observers is the repertoire of nonverbal responses that children often exhibit (e.g., facial expressions, eye contact, hand gestures, body movements, and reaction time in answering questions). However, unlike verbal cues that have been assumed to provide information about a speaker's thoughts, nonverbal cues have traditionally been assumed to reflect the speaker's feelings (Friedman, 1979, p. 3) and have been extensively studied in conjunction with emotion. For example, Buck (1975) showed that 4- to 6-year-old children produce facial expressions and gestures that provide interpretable information about their emotional reactions and affective states.

The question we ask here is whether nonverbal cues can provide information, not only about a child's attitudes toward a task, but also about that child's level of understanding of the task. Recent research has shown that experimenters can indeed use nonverbal cues to determine whether a child has understood a message, lesson, or instruction. For example, Patterson, Cosgrove, and O'Brien (1980) observed children 4, 6, and 8 years old in a referential communication game and found that children at all three ages produced different patterns of nonverbal behaviors for informative messages (which they presumably understood) versus uninformative messages (which they did not understand). The children took longer to respond, shifted their bodies more frequently, and moved their hands more often in response to uninformative messages than to informative messages. Similarly, Machida (1986) found that first graders exhibited less direct eye contact with the speaker, more head tilting, excessive hand movements, and agitated body movements when listening to a difficult lesson than when listening to an easy one. Flavell et al. (1981) found that both kindergarten and second-grade children produced distinctive nonverbal behaviors (e.g., facial, manual, and bodily expressions of puzzlement, manual vacillation, hesitations, and pauses in activity) when asked to follow inadequate instructions (see also Allen & Feldman, 1976).

Experimenters have not only used nonverbal behavior to determine whether a child has understood a message but have also relied on nonverbal behavior to provide insight into a child's mental representation of that message. Experimenters have used one particular type of nonverbal behavior—gestures made with the hands while speaking—as the basis for inferences about the speaker's mental representation. These hand gestures, called *illustrators* in Ekman and Friesen's (1969, 1972) system for classifying nonverbal behavior, often enact in movement the same ideas that can be encoded in speech (Kendon, 1980). For example, McNeill (1987) found that adults use hand gestures to portray concrete images (e.g., actions or attributes of cartoon characters) as well as abstract concepts (e.g., mathematical concepts of quotients, factors, or even limits in calculus). Children, too, often use hand gestures as they speak (Jancovic, Devoe, & Wiener, 1975), particularly when asked to explain their responses to a problem, and these gestures can provide the experimenter with insight into the way children represent problems (cf. McNeill, 1987, 1992). For example, Evans and Rubin (1979) taught children between the ages of 5 and 10 years to play a simple board game and then asked the children to explain the game to an adult. The children's verbal statements of the rules were routinely accompanied by gestures, and approximately half of the gestures the children produced supplied information that was not found in the verbal communication.

As a second example of gesturing in children, Church and Goldin-Meadow (1986) found that, when asked to explain their judgments on a series of Piagetian conservation tasks, all of the children in the study gestured spontaneously while speaking and portrayed specific aspects of the conservation task in their gestures. For example, in a task probing conservation of liquid quantity, a C-shaped hand was used to indicate the width of the dish, or a fist hand arced from the glass to the dish was used to indicate that the water had been poured from the glass into the dish. Often the information conveyed in gesture matched (or was a subset of) the information conveyed in the speech accompanying the gesture. As an example of a gesture–speech match for the liquid quantity conservation task, one child focused on the height of the water both in speech ("there is less water in the dish because the dish is short and the glass is tall") and in gesture (the child demarcated the heights of the two containers of water with his palm).

The gestures produced by the children, however, did not always convey the same information as the speech accompanying those gestures. At times, the information conveyed in gesture differed from and supplemented the information conveyed by the child's verbal response. As an example of a gesture–speech mismatch in the liquid quantity conservation task, one child focused on the height of the container in speech ("the dish is lower than the glass") but on the width of the container in gesture (the child produced a wide C-hand near the dish and a narrower C-hand near the glass).

Focusing on the relation between the information found in speech and gesture, Church and Goldin-Meadow (1986) found that the children in their study varied in the number of gesture–speech mismatches they produced, with some producing none and some producing as many as six (out of a possible six). Moreover, the children who produced many gesture–speech mismatches in their explanations of the conservation task were found to be more likely to benefit from instruction in conservation than the children who produced few gesture–speech mismatches. Perry, Church, and Goldin-Meadow (1988) similarly found that children who produced many gesture–speech mismatches in their explanations of a series of addition problems were more likely to benefit from instruction in mathematical equivalence than were children who produced few mismatches. Thus, to the trained eye of an experimenter, gesture can provide information about a child's knowledge of a task and, when interpreted in relation to speech, can serve as an index of the child's receptivity to instruction in that task.

The question naturally arises whether noninvestigators (e.g., teachers or other adults who are not trained observers of gesture) can take advantage of the information conveyed in gesture to assess the state of a child's knowledge of a concept and modify their responses to the child accordingly. Unfortunately, little is known about the adult's ability to decode or utilize children's nonverbal behavior. Jecker, Maccoby, Breitrose, and Rose (1964) found that junior high school teachers were unable to read students' nonverbal cues in a classroom situation, although the teachers could be trained to recognize and interpret their students' nonverbal cues (cf. Jecker, Maccoby, & Breitrose, 1965). In contrast, Machida (1986) explored the degree to which first-grade teachers were sensitive to the eye, hand, body, and head movements made by young children of various cultural backgrounds and found that the teachers were able to interpret these nonverbal cues as evidence of a child's understanding (or lack of understanding) of a problem. Machida did not determine, however, whether the nonverbal behaviors provided the teachers with any specific information about a child's knowledge of the problem.

The purpose of this study is to ask whether individuals who have not been trained to observe and code gesture can detect and interpret the gestures a child produces along with speech and use that information in appraising specific aspects of that child's knowledge. To meet this goal, we asked untrained adults to view a preselected series of videotaped vignettes, each portraying a different child responding to a Piagetian conservation task, and to assess each child's understanding of that task. The vignettes were selected so that half portrayed children producing explanations in which the information conveyed in gesture and speech was the same (i.e., gesture–speech matches) and half portrayed children producing explanations in which gesture conveyed information not found in speech (i.e., gesture–speech mismatches). Three questions were asked about the untrained adults' appraisals of the children's knowledge:

1. Do adults alter their own gestures when appraising children who produce gesture–speech mismatches?
2. Does the content of adults' responses (in gesture, speech, or both), when evaluated in relation to the reasoning expressed in children's spoken communications, differ for children who produce gesture–speech matches versus mismatches?
3. Do adults incorporate information from children's gestures into their own responses, and, if so, do they translate this information into speech?

METHOD

Subjects

Twenty adults participated in the study. None of the subjects had had any training in coding gesture, and none was aware of our interest in gesture. The subjects were drawn from two groups of adults: (a) 10 adults (8 women, 2 men) who were elementary school teachers in the Chicago area and (b) 10 adults

(7 women, 3 men) who were undergraduate students at the University of Chicago and had an interest in becoming teachers. No differences between the two groups of adults were found in any of the analyses reported later, and, as a result, the data were collapsed across the groups.

Procedure

The subjects were told that the purpose of the study was to explore the assessments adults make of a child's knowledge based on very short looks at the child explaining an answer to a task. Before viewing a series of videotaped vignettes, each adult was familiarized with the three different Piagetian conservation tasks portrayed on the videotapes (one task testing conservation of liquid quantity, one testing conservation of number, and one testing conservation of length; see Church & Goldin-Meadow, 1986, for details of the tasks). Props were used to explain each task.

Subjects were tested individually and saw a stimulus tape (see the following) containing a series of vignettes of 12 different children; each vignette was shown twice in order to ensure that the tape could be heard and seen clearly. After each vignette, the experimenter placed the props used in the task (a glass and a wide dish, checkers, or sticks) in front of the adult subject and asked the subject to give the experimenter a sense of the child's reasoning on this particular task. To make it more likely that the adult subjects would focus attention on each individual child on the videotape, the subjects were also asked to consider how they might go about teaching the concept to this particular child and to rate the child on a scale from 1 to 10 (with 10 being highest) on two different dimensions: confidence (How confident do you think this child is of his or her judgment and explanation?) and ease of training (How hard do you think it would be to teach this child conservation?). Each adult's response to each vignette was videotaped. The entire procedure took approximately 30 min.

Stimulus Tape

The stimulus tape portrayed 12 different children, each responding to an experimenter's request to justify their judgments on a single conservation task: 4 children participating in a liquid conservation task, 4 in a number conservation task, and 4 in a length conservation task. The vignettes showed each child responding to the conservation question (e.g., "Are the sticks the same length or different lengths? Why do you think so?"). Because we were interested in adults' appraisals of children who had not yet acquired the concept, the vignettes were chosen to include only those children who gave nonconserving (i.e., different) judgments on the task. Thus, each vignette showed the child stating his or her belief that the transformed object contained a different amount from the untransformed object. The vignettes were also selected so that all of the children gave nonconserving spoken explanations; that is, all of the children in both groups argued that, after the transformation, the object no longer had the same amount (e.g., on the liquid quantity task, one child said, "because this one is fatter and this one is skinnier" to explain why he thought the two containers held different amounts of water).

In addition, the vignettes were chosen so that six children produced gestures that matched their nonconserving spoken explanations (called *matching stimuli*), and six children produced gestures that did not match their nonconserving spoken explanations (called *mismatching stimuli*). The six matching stimuli portrayed 2 children each participating in a single length task, 2 participating in a single number task, and 2 participating in a single liquid quantity task, as did the six mismatching stimuli. As an example of a matching stimulus on a length task, a child in one of the vignettes explained that the two sticks were a different length by focusing on the transformation the experimenter performed both in speech ("you moved them") and in gesture (the child moved his hand along the table as though to push one of the sticks over).

There were two types of mismatching stimuli (three of each type) on the stimulus tape. In the first type, speech conveyed a nonconserving rationale, and gesture conveyed a conserving rationale. As an example from a number task, a child in one of the vignettes explained in speech that the transformed row had a different number "because you moved them" but conveyed in gesture an awareness of one-to-one correspondence (he pointed to a checker in one row and then to the corresponding checker in the other row and repeated this gesture with another pair of checkers). In the second type of mismatching stimulus, speech and gesture both conveyed nonconserving rationales, but the particular rationales differed. As an example from a liquid quantity task, a child in one of the vignettes focused on the difference in the heights of the dish and the glass in speech ("because this one's lower than that one") but focused on the difference in the widths in gesture (she placed a wide C-hand near the dish and a narrower C-hand near the glass).[1] We found no differences in the adults' reactions to the mismatching stimuli in which gesture conveyed a conserving rationale versus those in which gesture conveyed a nonconserving rationale; as a result, the data were collapsed across the two types of mismatching stimuli.

It is important to stress that the spoken judgments were incorrect in each of the 12 stimulus vignettes and that the spoken explanations for each of those judgments were nonconserving. The only consistent difference between the matching and mismatching stimuli was whether gesture conveyed the same information as

[1]The videotaped vignettes of the children were culled from data from a doctoral dissertation exploring the relation between gesture and speech as an index of cognitive stability (Church, 1987). Reliability in coding gesture and its relation to speech in the children's explanations was rather high: between 87% and 100% agreement between two coders for isolating and describing the gestures, and 88% agreement between two coders for coding the match and mismatch between gesture and speech.

the nonconserving spoken explanation (matching stimuli) or different information (mismatching stimuli). Thus, if the adult subjects responded differently to the matching versus the mismatching stimuli, this difference must reflect an ability to detect information conveyed solely in gesture.[2]

Two random orders of matching versus mismatching stimuli were prepared. Half of the adults were shown one order, and half were shown the alternate order. No differences were found in the responses to the two orders, and, as a result, the data were collapsed across the orders.

Coding and Analysis

We coded the adults' descriptions of each child's reasoning, focusing first on the verbal component of those descriptions. We coded the types of explanations expressed in speech according to the system described in detail in Church and Goldin-Meadow (1986). We then determined whether the adults produced spontaneous gestures with each of their spoken descriptions. If so, we determined whether the information conveyed in the adults' gestures was the same as the information conveyed in their accompanying speech; that is, we determined whether the gestures the adults produced matched or mismatched their spoken descriptions (see Church & Goldin-Meadow, 1986, for the details of this coding procedure).

In addition, we evaluated the adults' descriptions of the children's reasoning in relation to the children's verbal accounts of their own reasoning, categorizing the adults' responses into (a) repetitions of the child's verbal reasoning, (b) elaborations of the child's verbal reasoning, and (c) additions to the child's verbal reasoning.

Intercoder reliability was assessed by having a second observer recode the descriptions of each vignette produced by a randomly selected subset of the adult subjects. Both the original coder and the second coder classified adult responses to a vignette without knowing whether the child in that vignette produced a gesture–speech match or mismatch. Intercoder agreement was 89% (n = 116) for coding the relation between gesture and speech and 90% (n = 60) for categorizing responses as repetitions, elaborations, or additions. All of the data were analyzed using paired t tests, comparing responses of the adults to matching versus mismatching stimuli.

[2]It is, of course, possible that the children on the vignettes who produced gesture–speech mismatches differed from those who produced gesture–speech matches on some other dimension (e.g., attractiveness, politeness). When we examined the average ratings produced by the adult subjects on two of the questions included to focus the adults' attention on each individual child in the vignettes, however, we found that the adults rated the children who produced gesture–speech mismatches no differently from the way they rated the children who produced gesture–speech matches on both the confidence question (7.3 vs. 7.1) and the ease of training question (5.4 vs. 5.3). This lack of difference in ratings suggests that the particular vignettes chosen to represent children with gesture–speech matches versus mismatches were not so glaringly distinct as to elicit different assessments of the two groups of children no matter what the question.

RESULTS

Uncertainty in the Adults' Assessments of the Child's Reasoning

The primary goal of this study was to investigate if an adult—even one who has not been trained in coding gesture—appraises a child's knowledge of conservation differently, depending on whether that child produces gestures that convey information that is not conveyed in his or her spoken explanations of conservation. We hypothesized that adults might alter their own gestures in their appraisals of a child who produced information in gesture that could not be found in that child's speech. More specifically, we reasoned that, if an observer were able to interpret the information conveyed by gesture in a child's explanations, that observer might find it difficult to characterize the knowledge of a child who conveyed different information in gesture than in speech. This difficulty should lead the observers themselves to become uncertain—and therefore produce more of their own mismatches—when describing children who produced gesture–speech mismatches. Our first step in testing this prediction was to determine whether the adults in this study produced more of their own mismatches between gesture and speech when describing children who produced gesture–speech mismatches than when describing children who produced gesture–speech matches.

We first asked whether the adults gestured at all when assessing the children's reasoning and found that they gestured in 68% of their 236 responses.[3] We then asked how many of those gestures were mismatches and when those mismatches occurred. Figure 1 displays the proportion of responses in which the adults produced mismatches when appraising the six matching stimuli and the six mismatching stimuli and shows that the adults produced significantly more gesture–speech mismatches when describing children with mismatching explanations than when describing children with matching explanations (.39 vs. .18), $t(19) = 3.0, p \leq .007$.

The types of gesture–speech mismatches the adults produced were, not surprisingly, related to the types of mismatches portrayed in the stimulus tape. In both of the mismatching examples for the liquid quantity task, the children on the videotape focused on a dimension of the object rather than on the action performed on the object. In one vignette, the child produced a compensation rationale in gesture (contrasting the increase in height with the decrease in width) but focused on an entirely different dimension in speech (volume); in the second vignette, the child focused on the differences between the two objects in one dimension in gesture (width) and a different dimension in speech (height). In the

[3]Four of the 240 responses were lost due to equipment failure.

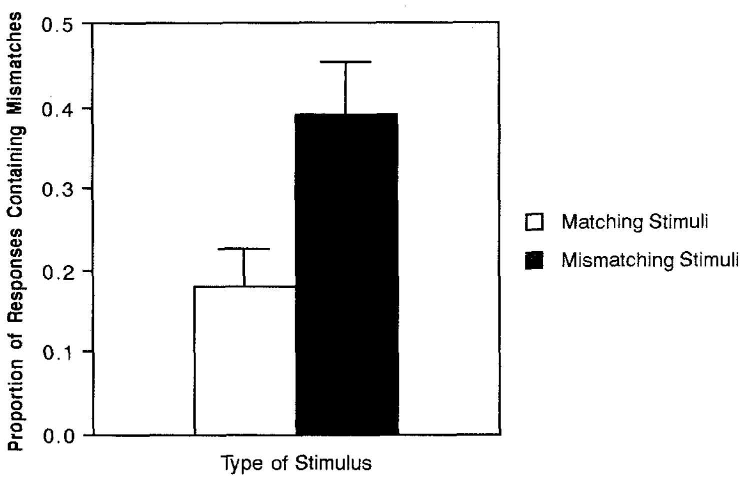

FIGURE 1 Proportion of gesture–speech mismatches produced by adults when appraising the knowledge of children whose gestures matched their speech (matching stimuli) versus children whose gestures did not match their speech (mismatching stimuli).

gesture–speech mismatches the adults produced in response to these vignettes, the adults tended to produce responses that also focused on the dimensions of the objects: 86% of the 21 mismatches the adults produced for the liquid quantity vignettes were ones in which gesture and speech each conveyed a different dimension or in which gesture conveyed the dimension conveyed in speech plus an additional dimension.

In contrast, in the mismatching examples for both the length and the number tasks, the children on the stimulus videotape focused on the actions performed on the objects as well as on the dimensions of the objects. In all four vignettes, the child commented in speech on the fact that the experimenter had moved the object in some way; in the accompanying gesture, the child conveyed a one-to-one correspondence rationale in one vignette, a reversibility rationale in another vignette, and focused on a dimension of the object (orientation or length) in the last two vignettes. The majority (64%) of the 47 gesture–speech mismatches the adults produced in response to these four vignettes referred to the action the experimenter performed on the object in one modality and to a dimension of the object in the other modality (the action was conveyed in gesture in approximately half of the responses and in speech in the other half).

That the adults produced more of their own mismatches when appraising the six children who produced gesture–speech mismatches than when appraising the six children who produced gesture–speech matches suggests that the adults were sensitive to the presence of gesture in the children's explanations of conservation. We next asked whether the adults used the child's gestures to glean specific information about that child's understanding of conservation.

Content of the Adults' Assessments: Does It Go Beyond the Child's Verbal Responses?

We evaluated the content of the adults' responses (as expressed either in speech or in gesture) in relation to the reasoning expressed in the child's spoken explanations. We found that the adults' responses could be divided into one of three categories.

1. *Repetitions of the child's verbal reasoning:* The adult's description (in gesture, speech, or both) expressed only the reasoning articulated by the child in his or her spoken explanation. For example, when describing a child who said the two sticks were different "because that one, you moved that one over," the adult stated, "The child said 'different' because [the experimenter] pushed one over." In the typical repetition, the adult repeated the information conveyed in the child's speech, and, if the adult gestured, the gestures conveyed that same information (i.e., the responses tended to be gesture–speech matches).

2. *Elaborations of the child's verbal reasoning:* The adult's description (in gesture, speech, or both) repeated the reasoning reflected in the child's spoken explanation and elaborated on that reasoning based on the test question asked by the experimenter who interacted with the child on the videotape. Two types of elaborations were found. First, the adult referred to the particular dimension (i.e., length, amount, or number) mentioned in the experimenter's question to the child (e.g., "Do the sticks have the same length or different lengths?") but not in the child's response. For example, when describing the child who said the two sticks were different "because that one, you moved that one over," an adult said, "he thought the sticks were different *lengths* because the experimenter moved one stick over." Second, the adult mentioned the comparative component of the task, again highlighting the dimension referred to in the experimenter's question. In describing the same vignette as before, another adult's response was, "You moved it and he felt that one appeared *longer*" (the adults used the words "more–less" and "higher–lower" for this type of elaboration in the number and liquid quantity tasks). An elaboration could be a gesture–speech match if gesture conveyed the same (or a subset of the) information conveyed in speech and if that information elaborated on the reasoning reflected in the child's spoken explanation in the ways described earlier. An elaboration could also be a gesture–speech mismatch, but this type of response was infrequent.

3. *Additions to the child's verbal reasoning:* The adult's description (in gesture, speech, or both) added elements to the child's reasoning that were not found in either the child's or the experimenter's speech. For example, on the number task, a child in one of the vignettes said that the rows of checkers were different " 'cause you moved 'em." When one of the adults described this child's reasoning, she added information that suggested that the child had some awareness of the principle of one-to-one correspondence: "It looked like initially he was matching them

up. He saw that they were the same and then when [the experimenter] moved them, it looked like he was seeing that they didn't match up any more." An addition could be a gesture–speech match if the adult's gesture and speech conveyed the same information and some of that information could not be found in the child's verbal reasoning, or an addition could be a gesture–speech mismatch if the adult's gesture and speech conveyed different information, some of which was not in the child's verbal reasoning. If a response contained an elaboration as well as an addition, that response was coded as an addition (49% of the adults' 87 additions also contained elaborations).

Figure 2 presents the proportion of responses in which the adults produced repetitions, elaborations, and additions for children with gesture–speech matches and for children with gesture–speech mismatches. Focusing first on repetitions, we found that the adults repeated the information conveyed in the child's spoken explanation with no alterations significantly more often when the child's gesture and speech matched than when the child's gesture and speech did not match (.39 vs. .25), $t(19) = 2.8$, $p \leq .01$.

Turning next to the responses in which the adults used the experimenter's test question to elaborate on the child's verbal reasoning, we found that, although the adults produced more elaborations in response to matching stimuli than mismatching stimuli (.34 vs. .28), this difference was not significant, $t(19) = 1.4$, ns.

Finally, as Figure 2 shows, the adults produced significantly more additions in response to mismatching than matching stimuli (.48 vs. .28), $t(19) = 4.2$, $p \leq .0004$. In other words, the adults were much more likely to add to the informa-

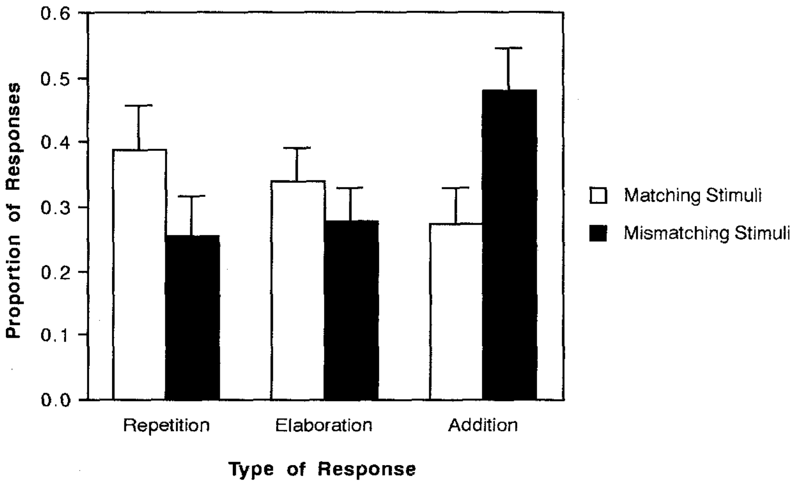

FIGURE 2 Proportion of responses that were repetitions, elaborations, or additions of the child's verbal reasoning produced by adults when appraising the knowledge of children whose gestures matched their speech (matching stimuli) versus children whose gestures did not match their speech (mismatching stimuli).

tion conveyed in the child's spoken explanation when the child's gesture and speech did not match than when they did.

Where Do Additions Come From and Where Do They Appear?

By definition, in the matching explanations of the children on the stimulus tape, the gestural information was identical to the verbal information. Thus, any additions produced by the adults in their descriptions of these explanations could not have been derived from information conveyed by the gestures of the children. In contrast, in the mismatching explanations on the stimulus tape, the children's gestures, by definition, conveyed information that was different from the information conveyed in their speech. We hypothesized that the additions produced by the adults in response to mismatching explanations might be traced back to information present in the children's gesture.

We found that 64% of the 55 additions the adults produced in response to mismatching explanations could, in fact, be traced back to the children's gestures.[4] For example, in the checker task, a child in one of the vignettes said that the rows had different numbers of checkers after one had been spread out "because you moved 'em," but in gesture he indicated that the checkers in one row could be matched in a one-to-one fashion with the checkers in the other row (he pointed to a checker in one row and then to the corresponding checker in the other row and repeated this gesture with another pair of checkers). The adult described the child as saying "You moved 'em, but then he pointed. . . . He was matching them even though he wasn't verbalizing it," while producing a one-to-one correspondence gesture of her own. Thus, the adult had attributed to the child reasoning that was explicitly mentioned in the child's speech (i.e., reasoning based on the fact that the checkers had been moved), along with reasoning that appeared only in the child's gesture (i.e., reasoning based on one-to-one correspondence).

One might, of course, hypothesize that the adults whose additions were based on the child's gestures did not actually decode the information conveyed in the children's gestures but merely mimicked the children's gestures without processing them. However, the data do not support this hypothesis, for whenever the adults incorporated information from the children's gestures into their own responses, they always translated that information into speech (see the previous example in which the adult translated into speech the one-to-one correspondence

[4]It is possible that the adults generated these additions not on the basis of the gestures produced by the children on the stimulus tape but, rather, on the basis of their own general knowledge of conservation. However, we think this is unlikely. When we analyzed the six rationales conveyed only in gesture in the children's mismatching explanations on the stimulus tape, we found that the adults produced these rationales more often in their additions to the mismatching stimuli than in their additions to the matching stimuli.

reasoning conveyed only in the child's gesture). One hundred percent of the adults' 35 additions that were based on the children's gestures were translated into speech (i.e., the additions were expressed either in speech alone or in gesture and speech together). These results strongly suggest that the adults were not simply mimicking the form of the children's gestures but rather had incorporated their content.

DISCUSSION

Although verbal cues and responses are assumed to be closely tied to a speaker's thoughts, nonverbal cues have traditionally been assumed to reflect the speaker's feelings (Friedman, 1979, p. 3). As a result, studies of how individuals interpret nonverbal behavior have focused almost exclusively on the ability to infer feeling or attitude from nonverbal cues. For example, Ekman, Friesen, and Ellsworth (1972) investigated whether individuals can interpret the emotional content of a given facial expression and found that, without special training, people are able to obtain information about happiness, surprise, fear, anger, disgust or contempt, interest, and sadness from the faces of other people. Rosenthal, Hall, DiMatteo, Rogers, and Archer (1979) extended the range of nonverbal behaviors to include body movements and hand movements and explored the effect of these behaviors on a listener's perception of a speaker's attitude.

In addition to exploring nonverbal cues to a speaker's attitude in the absence of speech, several studies have investigated how nonverbal cues are interpreted when they either agree or conflict with verbal cues to the speaker's attitude. Nonverbal cues to attitude have been studied in relation to two different types of verbal cues to attitude: (a) manipulations of voice quality independent of the content of the message (e.g., the word *maybe* uttered as though to communicate like, neutrality, or dislike; Mehrabian & Ferris, 1967; also see Blanck, Rosenthal, Snodgrass, DePaulo, & Zuckerman, 1982; DePaulo, Rosenthal, Eisenstat, Rogers, & Finkelstein, 1978) or (b) manipulations of the message itself (e.g., "You really did a fine job" vs. "You're a complete idiot"; Bugental, Kaswan, & Love, 1970; also see Friedman, 1978). These studies have found that untrained listeners are sensitive to the information conveyed in both the verbal and the nonverbal channels and make judgments about a speaker's attitude based on both channels.

Data from the present study suggest that untrained listeners not only use the information conveyed in both verbal and nonverbal channels to formulate opinions about speakers' feelings but also to glean information about speakers' knowledge of concepts. In this study, the gesture in the children's matching explanations added no new information to the children's speech and, therefore, provided little impetus for the adult to augment the children's verbal explanations of their understanding of conservation. In contrast, the gesture in the children's mismatching explanations did convey new information relative to the children's speech and could have provided impetus for an adult to augment the children's verbal explanations of their knowledge—but only if the adult were able to interpret those gestures. Indeed, we found that the adults in this study did augment the verbal explanations produced by children whose gestures conveyed different information from their speech. Moreover, the additional information about a child's knowledge that the adults conveyed could, for the most part, be traced directly to that child's gestures. Finally, the fact that the adults uniformly translated the information conveyed in the child's gestures into their own speech makes it clear that the adults were not merely mimicking the form of those gestures but had indeed interpreted their content.

McNeill (1987, 1992) has argued that the gestures people produce while speaking do not stand on their own and are interpretable only within the framework provided by speech; that is, these gestures form a single integrated system with speech and do so even at the earliest stages of language acquisition (see Morford & Goldin-Meadow, in press).[5] According to McNeill, gesture and speech *cooperate in conveying meaning, each providing an important channel of observation* into the mental processes and representations of the mind. Within this integrated system, gesture—being less codified than speech and dictated by different constraints (see Goldin-Meadow, in press; McNeill, 1992)—may reflect different kinds of knowledge than does speech. Gesture may, for example, provide a window into knowledge that is tacit and less reflected upon than the knowledge conveyed in speech. Indeed, our previous work has shown that the information conveyed in gesture, when interpreted along with speech, can provide insight into the internal processes that characterize the mind of a child in a transitional knowledge state, revealing the implicit as well as the explicit strategies children activate when tackling a problem (Goldin-Meadow, Nusbaum, Garber, & Church, in press). Thus, gesture, taken in conjunction with speech, may reveal the tacit hypotheses the child in transition is entertaining and, thus, may provide a window into the areas in which the child is ready to profit from instruction, that is, into the child's zone of proximal development.

In Vygotsky's (1978, p. 86) account of development, the *zone of proximal development* is defined as the distance between what children can do on their own and what they can do with the guidance of an adult or a more capable peer. Development is powered by the child's internalization of the cognitive processes shared in the zone of proximal development. However, it is unclear in this account how an adult is able to zero in on a child's zone of proximal development. We suggest that the spontaneous gestures children produce when communicating with adults provide an observable—and, as we have shown here, an interpret-

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[5]It is worth noting, however, that gesture can, under certain circumstances, be completely independent of speech, assuming the primary burden of communication on its own (e.g., the gestures produced by monks who have taken a vow of silence [see Wundt, 1973] or the self-styled gesture systems generated by deaf children who have not been exposed to sign and who use gesture as their primary means of communication [Goldin-Meadow & Mylander, 1990]).

able—index of the zone of proximal development and, thus, provide a mechanism by which adults can calibrate their input to a child's level of understanding.

It is worth noting that the adults in this study were not necessarily aware of the fact that they were noticing and interpreting the children's gestures. It may not be necessary, however, for adults to be explicitly aware of a child's gesture in order to change their input to the child on the basis of those gestures. For example, as described before, one of the children in the vignettes in this study indicated in speech that the rows had different numbers of checkers after one had been spread out "because you moved 'em," but, in gesture, the child indicated that the checkers in one row could be matched in a one-to-one fashion with the checkers in the other row. In her verbal assessment of this child's knowledge, one adult subject attributed to the child reasoning based on one-to-one correspondence (which appeared only in the child's gesture) as well as reasoning based on the fact that the checkers had been moved (which appeared in the child's speech). If this adult were to interact with this particular child, the adult might be expected to act as though the child understood one-to-one correspondence, as indeed, at some level, the child did. Being treated as though he understood one-to-one correspondence might be sufficient to force the child to realize that one-to-one correspondence was one of the hypotheses he activated on the conservation task and to encourage the child to integrate this hypothesis with his other, more explicitly stated, view of the concept.

The fact that the adults were sensitive to the information conveyed in a child's gesture suggests that it is not necessary to be trained in gesture coding to be responsive to the information conveyed in gesture in a child's explanations and to make use of this information in forming judgments about a child's knowledge. It is certainly possible, however, that instruction in attending to and interpreting gesture might significantly improve an adult's access to the information available in gesture. Indeed, researchers have been successful in training adults to make better use of nonverbal cues in their judgments of children's comprehension. For example, Machida (1986) found that raters trained to tally the occurrence of eye contact with the speaker and of head, mouth, body, and hand movements were more accurate in assessing a child's comprehension than were untrained first-grade teachers. Similarly, Jecker et al. (1965) found that student teachers, after being trained to recognize and interpret a set of nonverbal cues, became better able to use those cues in making judgments of student comprehension. Training of this sort might be of great benefit to educators given that gesture, when interpreted in relation to speech, has been shown to provide a more accurate picture of the stability of a child's knowledge of a task and his or her readiness to profit from instruction in that task than speech taken alone (Alibali & Goldin-Meadow, 1992; Church & Goldin-Meadow, 1986; Goldin-Meadow, Alibali, & Church, in press; Perry et al., 1988, 1992).

The data from this study suggest that, in an experimental setting, adults who are not trained in coding gesture can interpret information expressed in children's gestures. We recognize, however, that by asking the adults in our study to concentrate on a small segment of behavior on a videotape monitor we provided them with maximum opportunity to focus on the child's gestures and speech. Thus, it is not clear from these data whether in a naturalistic setting adults really would process and interpret children's gestures. In addition, our study does not address whether adults used the information they extracted from children's gestures to modify the way in which they interacted with those children. In a study of four mothers' responses to the object-related gestures produced by their first-born infants, Masur (1982) found that the mothers responded differentially to their children's pointing gestures, providing labels for the indicated objects (also see Shaw, 1991). These data suggest that adults do make use of children's gestures in determining what their input to a child will be. In our own work, we are currently asking adults who have not been trained in gesture coding to instruct children on an individual basis in a particular concept. Preliminary results indicate that adults offer different types of instruction to children whose gestures convey information not found in speech as opposed to children whose gestures convey the same information as speech (Church, Momeni, Williams, Garber, & Goldin-Meadow, 1992). These observations, if borne out, suggest that, in a relatively naturalistic setting, adults not only interpret the information conveyed in a child's gestures but also utilize that information in deciding how to instruct the child.

The fact that untrained observers can interpret gesture that accompanies speech in a child's explanations paves the way for the possibility that gesture–speech mismatch plays a role in the mechanism of cognitive change – not necessarily in terms of its direct effect on the learner but perhaps indirectly in terms of its effect on the learning environment. The fact that the child is conveying information in gesture that is not found in speech may serve as a signal alerting the child's environment (including teachers, parents, more advanced peers) to adjust input to the child in such a way that the child receives crucial information for conceptual reorganization. Thus, children may play a role in shaping their own learning environments by providing feedback to their teachers through their production (or lack of production) of gesture–speech mismatches.

If, as previous studies suggest, children's gestures offer insight into the areas in which they are ready to learn, it becomes important both to inform teachers of this potential source of information and, if necessary, to give teachers guidance in decoding the information conveyed by gesture. Armed with a more complete assessment of a child's knowledge of a concept, a teacher might be better able to provide the input necessary to bring about qualitative change in that child's understanding of the concept. In addition, taking the child's point of view, it is worth noting that teachers themselves are likely to produce gestures in their explanations to a class, and those gestures undoubtedly convey information. If that information is interpretable to a child, it could either help or hinder the child in grasping a new concept. Indeed, in a study of 8- to 11-year-old tutors, Allen and Feldman (1976) found that the tutors did produce nonverbal behaviors and that these behaviors were accurately interpreted by other children. Thus, in addition to making teachers aware of their students' gestures, it may also be important to make teachers aware of their own gestures and of the impact these gestures might have on their students.

In sum, previous work has shown that the information conveyed in gesture, considered along with the information conveyed in speech, is an observable and interpretable reflection of a child's knowledge of a concept—observable and interpretable, that is, to experimenters trained in coding gesture. The data from the present study suggest that, even without training, adults pay attention to some of the rich information available in gesture and form impressions of a child's knowledge based not only on what children say with their mouths but also on what they say with their hands.

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