Tapping Toddlers' Evolving Semantic Representation via Gesture

Nina C. Capone
Seton Hall University, South Orange, NJ

Purpose: This study presents evidence that gesture is a means to understanding the semantic representations of toddlers.
Method: The data were part of a study of toddlers' word learning conducted by N. C. Capone and K. K. McGregor (2005). The object function probe from that study was administered after 1 exposure and after 3 exposures to objects. Here, toddlers' gestures were described and their gesture–speech combinations were analyzed as a function of instruction and time.
Results: A large proportion of toddlers gestured. Gestures were iconic and deictic, but toddlers produced more iconic gestures than previously reported. Consistent with studies of older children, toddlers produced gesture–speech combinations that reflected their learning state.
Conclusion: Gesture can be both a source of semantic knowledge and an expression of that knowledge. Gesture provides a window onto evolving semantic representations and, therefore, can be 1 method of assessing what a child knows at a time when oral language skills are limited and are, perhaps, an unreliable indicator of what the child knows. Embodied knowledge may underlie the use of gesture. Clinical implications are discussed.

KEY WORDS: gesture, semantic learning, toddlers

Evaluating what toddlers know presents a challenge to language scientists and clinicians. Children at this stage of development are limited in linguistic, metalinguistic, and articulatory skills. From infancy, children compensate for some of these limitations with gesture. When infants are at the one-word stage of development, they communicate with deictic gestures (e.g., pointing) and some single iconic gestures that function as words not found in their spoken repertoires (Acredolo & Goodwyn, 1988). For example, the child may see a ceiling fan and extend an index finger up, making a circling motion, to label it (Acredolo & Goodwyn, 1996). Later, the semantic relations expressed in gesture–speech combinations (e.g., *mommy* + point to chair) precede those same relations heard in spoken word combinations (e.g., *mommy chair*; Özçalişkan & Goldin-Meadow, 2005). These combinations suggest that the mental representation of early semantic relations is established sooner than speech alone would indicate (see also Goldin-Meadow & Butcher, 2003; Iverson & Goldin-Meadow, 2005). A child's gesture may also indicate what he or she has represented about a particular word. For example, Goldin-Meadow and Butcher reported that a young toddler produced palm movements that he scratched in the air while saying the word "bear" (p. 95). Here, we see that the child's mental representation of *bear* includes an upright clawing motion, a feature that may distinguish it from other animals. Therefore, attention to a child's gesture

1092-4388/07/5003-0732

may provide a broader window onto what a child knows and what may be on the cusp of mastery.

The current study extends the extant literature by examining the relationship between a toddler's gesture and speech as a function of semantic learning. Goldin-Meadow and colleagues (e.g., Alibali, Bassok, Solomon, Syc, & Goldin-Meadow, 1999; Alibali & Goldin-Meadow, 1993; Church & Goldin-Meadow, 1986; Perry, Church, & Goldin-Meadow, 1988) provide a rich literature on the gesture–speech relationship as a function of learning several mental representations (e.g., balance beam, conservation of quantity, mathematical equivalence, Tower of Hanoi puzzle, algebra word problems). The relationship between what is conveyed in gesture and what is conveyed in speech changes systematically as a child moves from an incomplete understanding to a complete understanding of a task. This relationship indicates where the child is in the process of learning a particular problem and can direct adults to their instruction on that task (Goldin-Meadow & Singer, 2003). Much of the literature reports on school-age children. The relationship between gesture and speech earlier in development is less explored, particularly whether gesture–speech combinations change as a function of a toddler's learning, with and without instruction. The aim of this article is to demonstrate that gesture can supplement speech when assessing what toddlers know about the words they are learning. Specifically, the evidence supports the view that gesture acts as a window onto a toddler's semantic representation.

Gesture–Speech Combinations Provide a Window Onto a Variety of Mental Representations

School-age children use gesture and speech in combination to express their understanding of tasks (e.g., Alibali & Goldin-Meadow, 1993; Church & Goldin-Meadow, 1986; Garber, Alibali, & Goldin-Meadow, 1998; Garber & Goldin-Meadow, 2002; Goldin-Meadow, 2000; Goldin-Meadow, Alibali, & Church, 1993; Kelly & Church, 1998; Perry et al., 1988; Pine, Lufkin, & Messer, 2004). In these studies, children solve a series of problems and explain their solutions. For example, Church and Goldin-Meadow tested 5- to 8-year olds on their knowledge of conservation of quantity. On one trial, they showed children two equivalent glasses of liquid and then poured one glass of liquid into a dish. Children were asked if the amount of liquid in the dish was equivalent to the liquid in the glass and then were asked to explain their response (e.g., "Why?" and "How can you tell?"; p. 47).

Across studies, children produce iconic and pointing gestures in their explanations. *Iconic gestures* convey meaning through the form, action, or spatial position of the body; these gestures are often hand movements (Goldin-Meadow, 2003; McNeil, 1992). *Pointing gestures* refer to contextually present components of a problem (e.g., pointing to numbers preceding an equivalence symbol to indicate that they are summed). Task solutions are analyzed for accuracy, and explanations are analyzed for occurrence of gesture–speech combinations, information expressed in each modality, and whether gestured information matches or mismatches spoken information. Three types of gesture–speech combinations are reported in the literature: (a) gesture and speech match but express inaccurate information, (b) gesture and speech mismatch (i.e., convey different information) and may contain at least one piece of accurate information, or (c) gesture and speech match, expressing accurate information. School-age children infrequently respond with gesture alone (e.g., 3% of responses; Church & Goldin-Meadow, 1986, p. 52).

Several characteristics of gesture–speech combinations allow adults a window onto the child's developing mental representations. Evidence suggests that when the child produces mismatch combinations, this reflects a transitional knowledge state (e.g., Alibali & Goldin-Meadow, 1993; Church, 1999; Perry et al., 1988). During this time of transition, it is believed that the child is moving from an incomplete understanding toward a complete understanding of a task and is considering multiple beliefs about the task's solution (Garber & Goldin-Meadow, 2002; Goldin-Meadow, Nusbaum, Garber, & Church, 1993). These beliefs are simultaneously activated as the child engages in thinking about the task. This leads to some of those beliefs being expressed in gesture and others being expressed in speech. For example, the child who understands that liquid quantity conserves may explain that "the glass is tall and skinny" whereas producing a pouring motion from the *dish* to the *glass* (Church & Goldin-Meadow, 1986, p. 58). Here, the child expresses three beliefs about why liquid quantity conserves: the compensatory features of the container's shape in two dimensions and the reversibility of the transformation.

Children who produce many mismatch combinations during their explanations are more likely to benefit from instruction on the task than are children who produce few to no mismatch combinations (e.g., Church & Goldin-Meadow, 1986; Perry et al., 1988). Mismatch combinations signal the transitional knowledge state that is described as unstable (Goldin-Meadow, 2000; Goldin-Meadow, Alibali, & Church, 1993). In Alibali and Goldin-Meadow (1993), children who produced mismatch combinations were more likely to advance to a correct understanding when provided instruction but also to generalize learning to untrained exemplars. Without instruction on a task, the child who produced mismatch combinations could regress to an inaccurate state of understanding. Further, children who received instruction but did not pass through a period of gesture–speech mismatch were less likely to generalize their knowledge to untrained exemplars. Gesture and speech that matched characterized the stable and accurate understanding of the task.

The learner's mismatch combinations are of use to the observer because gesture has access to knowledge that may not be heard in speech (Alibali et al., 1999; Evans, Alibali, & McNeil, 2001; Garber et al., 1998; Goldin-Meadow, Alibali, & Church, 1993; Pine et al., 2004). For example, Goldin-Meadow, Alibali, and Church found that children expressed more task solutions uniquely in gesture than in speech—that is, children had beliefs represented about the task's solution, but this knowledge would have gone unnoticed had only speech been assessed. In the study by Alibali and colleagues (1999), undergraduates explained solutions to algebra word problems. When gesture did not match speech, gesture was just as likely as speech to convey the strategy that the participant actually used to solve problems. Children with language impairments, a population with limited verbal language skills, also convey knowledge of conservation via gesture (Evans et al., 2001). Evans and colleagues found that children with language impairment expressed knowledge that was more advanced via gesture more often than did typically developing children who were matched for task accuracy. The child's gesture can have an indirect effect on his or her learning. Adults with and without training in coding gesture glean information from the child's gesture and tailor their instruction to the child accordingly (Goldin-Meadow & Singer, 2003; Kelly & Church, 1998; Kelly, Singer, Hicks, & Goldin-Meadow, 2002).

In sum, there is evidence that gesture provides a window onto developing mental representations. For school-age children, mismatch combinations can reflect a knowledge state that is in transition to full understanding of a task. The child is simultaneously activating multiple beliefs about a task, and these beliefs can be observed in gesture and speech. The child who produces mismatch combinations is more likely to benefit from instruction. *Benefit* has been characterized by a more advanced understanding of task solutions and better performance on trained and untrained task exemplars. The child who does not produce mismatch combinations may not be ready to advance his or her understanding to the same extent, even with instruction. Gesture conveys knowledge that may not be heard in speech, and the act of gesturing affects the child's learning environment. Less is known about the gesture–speech combinations produced by toddlers, particularly in regard to toddlers' learning.

Early Gesture Development

From infancy, gesture serves to supplement and predict spoken language skills (Capone & McGregor, 2004). Pointing precedes first words, and when first words emerge, pointing gestures and some single iconic gestures are also used to communicate. Within months, children combine gesture with words to express semantic relations (Capirci, Iverson, Pizzuto, & Volterra, 1996; Goldin-Meadow & Butcher, 2003; Iverson & Goldin-Meadow, 2005; Morford & Goldin-Meadow, 1992; Özçalişkan & Goldin-Meadow, 2005). The toddler's gesture–speech combinations have been characterized as *reinforcing combinations* or *supplemental combinations* and are consistent with those described in older children. *Reinforcing combinations* convey matching information (e.g., pointing to car + *car*), whereas *supplemental combinations* convey different or mismatched information cross-modally (e.g., reaching the hand out with palm up + *juice*). Toddlers use gesture in isolation more often than reported for older children. For example, Iverson and Goldin-Meadow (2005) reported that approximately one-half of object-referenced communication was a gesture in isolation, whereas the second half was split between speech alone and gesture–speech combinations. Also, toddlers use deictic gestures more often than they use iconic gestures (e.g., Capirci et al., 1996; Morford & Goldin-Meadow, 1992). Morford and Goldin-Meadow described *matched combinations* as predominately pointing or showing an object in combination with a noun, whereas mismatched gestures were (a) pointing or showing an object + [spoken action, adjective, or different noun] or (b) an action gesture or head nod + [noun]. Supplemental combinations have been positively correlated with expressive language skills (Capirci et al., 1996; Morford & Goldin-Meadow, 1992). It is not known whether mismatch combinations reflect a transitional knowledge state for toddlers comparable to what has been described in older children. One study is suggestive of this (Gershkoff-Stowe & Smith, 1997).

During the *word spurt,* a key period of transition in the developing lexicon, Gershkoff-Stowe and Smith (1997) reported that toddlers produced mismatch combinations in naming contexts. The instability of the lexicon during this transition was marked by a sharp rise in naming errors (see also Gershkoff-Stowe, 2001). Toddlers produced naming errors on referents that they previously had success in naming. These word retrieval errors were accompanied by pointing to pictured referents. They were considered gesture–speech mismatches because the pointing gesture did not indicate the spoken referent. Gershkoff-Stowe and Smith did not conduct a systematic analysis of gesture–speech combinations, and the learning context was not controlled for this purpose. In the current study, the gestures of toddlers studied by Capone and McGregor (2005) were analyzed. In this study, a brief course of word learning was experimentally controlled. It provided an opportunity for observing learners' progress from an incomplete semantic representation to a richer representation of the words that they were learning.

The Current Study

The current study examined toddlers' gestures during a brief course of word learning to determine whether gesture acts as a window onto their evolving semantic representations. The data were part of a study of toddlers conducted by Capone and McGregor (2005). In this study, Capone and McGregor tested whether richness of semantic representation influenced word retrieval (see also McGregor & Appel, 2002; McGregor, Friedman, Reilly, & Newman, 2002; and McGregor, Newman, Reilly, & Capone, 2002). Frequency of word exposure was controlled because the training objects and words were novel. The experimenter modeled object labels in all conditions. Semantic enrichment varied by condition. In the experimental conditions, the experimenter's iconic gestures cued the toddler's attention to the shape (shape condition) or function (function condition) of the object; no semantic cue was provided in the control condition. By the study's end, toddlers learned the same number of words under all learning conditions, but the quality of learning differed. Specifically, toddlers retrieved more words for naming (uncued, cued) under the experimental conditions than under the control condition. Conversely, toddlers' learning of control condition words was evident only within the most scaffolded task—the picture recognition task, which provided the child with a referent, a word label, and contrasting exemplars. Performance on a semantic probe paralleled these results. Specifically, toddlers named more object functions under experimental conditions than they did under the control condition. These results were explained within an associationistic account of the lexical–semantic system.

According to associationistic accounts, the lexical–semantic system consists of a distributed neural network of auditory, visual, tactile, proprioceptive, olfactory, and/or gustatory features (i.e., information nodes). Lexical and semantic nodes are activated and processed simultaneously. Simultaneous processing and the connections within the network allow for spreading of neural activation between semantic and lexical nodes (Barsalou, 1999a, 1999b; Barsalou, Simmons, Barbey, & Wilson, 2003; Plunkett, Karmiloff-Smith, Bates, Elman, & Johnson, 1997). Each node and connection carries an activation weight (excitatory or inhibitory) that sums at the lexical node. The threshold of activation will more likely be met for lexical retrieval of a richer semantic representation than for lexical retrieval of a weaker representation. The richer representation contributes greater summed activation at the lexical node (e.g., Bjorklund, 1987). An incomplete or weak semantic representation lacks distinction from other representations and/or connections between nodes; therefore, retrieval may be inaccurate because a competing lexical item reaches its activation threshold over the target item.

The word retrieval errors that children make in naming contexts are predominately semantic in nature (e.g., Gershkoff-Stowe & Smith, 1997; McGregor, 1997). McGregor and colleagues have demonstrated that accurate naming is positively correlated with rich semantic representations, and semantic naming errors are positively correlated with weak semantic representations of target words (McGregor, Friedman, et al., 2002; McGregor, Newman, et al., 2002). Capone and McGregor (2005) provided experimental evidence of the relationship between semantic representation and word retrieval. Because the learning context was controlled in that study, some predictions can be made about toddlers' use of gesture as they progressed from a weak representation to a richer representation of the words they were learning. Here, I re-examine Capone and McGregor's object function probe for a full repertoire of responses, cross-modally.

During the course of instruction provided by Capone and McGregor (2005), toddlers were queried about the functions of the objects they were learning (object function probe). This was done on a day after the first exposure to the objects (Visit 2) and on a day after the third exposure to the objects (Visit 4). In Capone and McGregor, we reported only spoken responses to the object function probe on the day that we tested word retrieval (Visit 4). In the current study, I first describe the toddlers' complete repertoire of responses across modalities. Next, I examine the relationship between gesture and speech by analyzing the occurrence of gesture–speech combinations over time as a function of the learning condition. Whereas Capone and McGregor reported on the effect of an *adult's* gestures on toddlers' lexical–semantic learning, the current article documents the *toddler's* gestures as a function of that learning.

The study questions are as follows: (a) What types of responses do toddlers produce when asked to state an object's function? (b) Do toddlers show a transition from gesture–speech mismatch to gesture–speech match combinations as they progress from a weak semantic representation to a richer semantic representation? (c) Is object function expressed via gesture before speech? Capone and McGregor (2005) controlled the participants' learning context. Initially, this placed toddlers in a weak state of semantic representation. By the study's end, there was evidence of richer semantic representation under experimental conditions but not under the control condition. Therefore, I predicted that under experimental conditions, there would be a decline in mismatch combinations and an increase in match combinations over time. I also expected that object function would be conveyed via the child's gesture more often than the spoken utterance within the mismatch combinations. This prediction was grounded in evidence that mismatch combinations index a transitional, unstable, knowledge state. If the child has not yet richly integrated a lexical–semantic representation, then function information may not yet be accessible to the spoken modality.

Methods

Participants

Eighteen of the 19 toddlers (M = 28.72 months, SD = 1.02 months, range = 27–30 months) who participated in the study by Capone and McGregor (2005) were studied here. One participant was excluded because video recordings were necessary for coding gesture data, and the child's mother denied videotaping for her child. Participants were monolingual, English-speaking toddlers (6 boys, 12 girls) from Chicago and its North Shore area. The participants were of African American (6%), Asian American (11%), and Caucasian American (83%) backgrounds. Participants had no history of hearing impairment or developmental delays. Consistent with the economic status of the recruitment area, mothers were highly educated (M = 17.5 years, SD = 1.34 years).

Stimuli

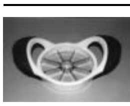
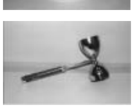
The six objects used for training were organized into three stimulus sets with two objects per set. Objects were distinct from one another in shape and function. A nonce label, nonce function, shape gesture, and function gesture were created for each object. The shape and function gestures were visual cues. They enriched semantic learning under experimental conditions (see below). The objects, their nonce labels, and their functions are listed in Table 1.

Procedure

The experimenter visited each participant in his or her home on 4 separate days. The first three visits were used for word learning instruction. Children learned nonce words to label the objects under three conditions: shape (SHP), function (FNC), and control (CTL). Spoken words labeled objects in all conditions, but a gesture highlighted either the shape (e.g., "It's a /dɑɪn/" + an iconic gesture that matched the shape) or the function (e.g., "It's a /dɑɪn/" + a fisted turning motion) of the object in the experimental conditions. No semantic cue was present in the control condition (e.g., "It's a /dɑɪn/"). During these first three visits, the experimenter demonstrated the objects' functions, and participants manipulated the objects. The experimenter labeled each object 9 times across the study but never spoke the functions of the objects.

Each word learning condition (SHP, FNC, CTL) was presented on each of the first three visits. The order in which conditions were presented was counterbalanced across children but was consistent across visits with any given child. Object sets were also counterbalanced between conditions across children. Word retrieval was assessed at the fourth visit. The object function probe was administered at Visits 2 and 4. At Visit 2, the object function probe was administered before word learning

Table 1. Trained objects, nonce labels, and nonce functions.

Trained object	Nonce label	Nonce function
	/paʊm/	Push down onto flattened Play-Doh, leaving a distinct imprint
	/kas/	Pick up a ball of Play-Doh
	/nɔɪb/	Roll across flattened Play-Doh, leaving a distinct imprint
	/gef/	Catapult Play-Doh from the shorter end when hitting the longer end
	/dɑɪn/	Flatten Play-Doh by turning the lid
	/wʌg/	Form a dumpling-shaped mass when moving from open to closed position.

instruction; therefore, toddlers had only one exposure to the objects. At the fourth visit, toddlers had three previous exposures to the objects.

Object Function Probe

Toddlers were asked to state each object's function in the object function probe. Each condition contained two objects. Thirty-six experimental trials were presented per condition across participants (18 participants × 2 objects = 36 trials/condition). Practice trials in which the experimenter queried the child about familiar objects (cup, ball, comb) preceded the experimental task. For practice trials and experimental trials, the experimenter showed each object and queried "What do we do with this one?" If a child did not respond to the query, the experimenter prompted the child, "Do we drink with this one? No, we drink with the cup ('cup' + sign). What do we do with this one?" For practice trials, if a child did not respond to the query, the experimenter modeled the response (e.g., "we throw a ball."). The child was praised regardless of response accuracy on all trials. All participants demonstrated understanding of the task by responding to at least one of the familiar object queries without a model.

Data Coding and Analysis

Spoken responses were transcribed verbatim. *Accuracy* was defined as spoken responses that uniquely described the function of an object. For example, functions such as "we scoop" for the /kɑs/ and "mix it" for the /dɑɪn/ were accurate because they were only characteristic of the target object's function. Generic actions (e.g., "play") were not specific to a particular object and, therefore, were not tallied as accurate in these analyses. Iconic and point gestures were tallied. Gestures were transcribed for motor movement (e.g., hands come to midline with palms facing each other, point to table). As with speech, gesture accuracy was defined by object-specific function.

Responses were categorized by modality type. A variety of response types were observed, including gesture alone, gesture–speech match combinations, gesture–speech mismatch combinations, and speech alone. See Table 2 for response examples. A gesture–speech combination occurred when a gesture and spoken utterance were expressed at the same time. Mismatch combinations were defined by each modality conveying different information. Match combinations were those in which both modalities expressed the same information. Information conveyed by speech or gesture included (a) accurate function information, (b) thematic information (e.g., pointing to the table to indicate its associated location, commenting "It's your thing" or "We use it with Playdoh"), (c) an object label, or (d) inaccurate function information. The Appendix contains coding rules and examples of combination types.

Only mismatch and accurate match combinations were included in these analyses because Alibali and Goldin-Meadow (1993) defined *accurate match combinations* as the stable end state of learning. Inaccurate match combinations were not analyzed. Consistent with the work of Goldin-Meadow and colleagues, mismatch and match combinations were analyzed for positive or negative gain in occurrence (i.e., increase or decline in occurrence, respectively). The change in occurrence, rather than the absolute level of occurrence, of these combinations was analyzed at Visit 4. This method is viewed as a more valid measure of learning because performance after instruction is relative to the level of knowledge before instruction is provided. Analyzing gain (i.e., increase or decline) accounts for the level of knowledge that a child has received preinstruction (Goldin-Meadow, Alibali, & Church, 1993, p. 281). I calculated gain for mismatch and match combinations separately by subtracting the frequency of combinations at Visit 2 from the frequency

Table 2. Sample responses to the object function probe.

Modality of response	Target object	Sample response provided by toddlers
Gesture (−)	/gef/	Point to table or /nɔɪb/ gesture
Speech (−)	/kɑs/	"We put that in Playdoh"
Gesture (−) Speech (−) match	/wʌg/	Scooping motion + "scoop it up"
Gesture (−) Speech (−) mismatch	/dɑɪn/	Flat hand down + "we roll it"
Gesture (+) Speech (−) mismatch	/wʌg/	Fisted hands move to midline + "we put Playdoh"
Gesture (−) Speech (+) mismatch	/dɑɪn/	Point to table + "you … smush it"
Gesture (+)	/paʊm/	Fisted hands moving down
Gesture (+) Speech (+) match	/nɔɪb/	Flat hand moving laterally + "we roll it"
Speech (+)	/dɑɪn/	"Turn it"

Note. (+) = accurate; (−) = inaccurate.

at Visit 4. Therefore, if a child produced two mismatch combinations at Visit 2 and no mismatch combinations at Visit 4, then there was a decline (i.e., negative gain) of two mismatch combinations (−2). The predicted pattern of change in gesture–speech combinations is a decline in mismatch combinations and an increase in accurate match combinations from Visit 2 to Visit 4 under experimental conditions (SHP, FNC) not under the control condition (CTL).

Reliability

An independent coder who was blind to the purpose of the study and hypotheses recoded 33% of the object function probes. Point-by-point agreement between the independent coder and the author was calculated for each dependent variable. Agreement in coding whether or not a child gestured was 100%. Agreement in coding responses as singleton iconic gestures, gesture–speech combinations, and speech-only responses was 88%. Agreement in coding a gesture as iconic or deictic was 93%. Agreement in coding occurrence of gesture under each learning condition was 94%. Agreement in coding gesture accuracy at Visit 4 was 86%. Agreement in coding a gesture–speech combination as mismatch versus match was 90%. Agreement in coding the accuracy of gesture and speech within gesture–speech mismatch combinations was 100%. The levels of agreement achieved here were consistent with other studies of gesture (e.g., Alibali & Goldin-Meadow, 1993; Church & Goldin-Meadow, 1986; Goldin-Meadow & Butcher, 2003; Özçalişkan & Goldin-Meadow, 2005).

Dependent Variables

The dependent variables were (a) the percentage of children who gestured, (b) the proportion of total responses that are singleton iconic gestures, gesture–speech combinations, and speech-only responses, (c) the mean number of iconic and pointing gestures produced, (d) the mean number of gestures produced under each learning condition, (e) the accuracy of gestured responses at Visit 4, (e) changes (increase or decline) in gesture–speech mismatch and match combinations, and (f) the accuracy of object function expressed in gesture versus speech within gesture–speech mismatch combinations.

Results

Describing Toddlers' Repertoire of Responses: What Types of Responses Do Toddlers Produce?

I first describe the participants' responses. Seventeen of the 18 participants (94%) gestured during one or both object function probes. They provided 166 responses across both object function probes. Of those 166 responses, 26% were gesture only, 35% were gesture–speech combinations, and 39% were speech only. Toddlers produced all possible combinations of gesture and speech, including inaccurate and accurate matches, mismatches in which both modalities expressed inaccurate information, and mismatches in which one modality expressed accurate information. Accurate and inaccurate information was expressed in gesture-only and speech-only responses. Gestured errors were semantic (e.g., pointing to the table, gesturing the function of another object) or prelexical in nature (e.g., pointing to the referent). Spoken errors were semantic or lexical in nature (e.g., labeling the object, stating an unspecified action such as *play,* stating thematic information such as *Playdoh,* or stating the action of another object).

Toddlers produced iconic and pointing gestures, but they produced significantly more iconic gestures ($M = 5.10$, $SD = 3.98$) than pointing gestures ($M = .44$, $SD = .78$) across both probes, $t(17) = 4.72$, $p < .001$, $d = 1.17$. Table 3 summarizes the mean number of gestures that the toddlers produced between conditions. As Table 3 illustrates, toddlers gestured (iconic and pointing gestures) comparably across visits in the SHP, FNC, and CTL conditions, $F(2, 34) = 1.87$, $p = .17$. When only iconic gestures were analyzed across visits, there were no between-condition differences, $F(2, 32) = 0.239$, $p = .79$. At Visit 4, Capone and McGregor (2005) reported that toddlers produced more spoken responses under the experimental conditions than under the CTL condition. Here, at Visit 4, toddlers gestured accurate functions comparably across the SHP, FNC, and CTL conditions, $F(2, 34) = 1.70$, $p = .20$.

In summary, almost all of the toddlers gestured during the object function probes. They produced gesture–speech combinations in addition to gesture or spoken utterances in isolation. More iconic gestures than pointing gestures were produced, overall, but toddlers were not more or less likely to gesture in any one condition.

Table 3. Mean number (and standard deviation) of gestures produced by the participants.

Gestures	Shape condition	Function condition	Control condition
Iconic and deictic gestures produced at Visits 2 and 4	1.72 (1.13)	2.11 (1.60)	1.67 (1.57)
Iconic gestures (accurate and inaccurate) produced at Visits 2 and 4	1.65 (1.32)	1.71 (1.53)	1.53 (1.5)
Accurate iconic gestures produced at Visit 4	.94 (0.80)	1.0 (0.97)	.67 (0.77)

Subsequent analyses examine the relationship between gesture and speech in their cross-modal combinations.

Gesture–Speech Combinations: Do Toddlers Show a Transition From Mismatch Combinations to Match Combinations?

Next, I examine the participants' change in gesture–speech combinations. It was predicted that a decline in gesture–speech mismatch combinations and an increase in accurate gesture–speech match combinations would be evident in the experimental conditions (SHP, FNC) but not in the CTL condition. Fourteen participants (78%) produced gesture–speech combinations. Twenty-eight trials were provided per condition across participants (14 participants × 2 objects). The frequency with which mismatch and match combinations occurred is presented in Table 4. Mean gain scores (i.e., increase or decline) for mismatch and match combinations are reported in Table 5. Gain scores were subject to a 2 (combination type) × 3 (condition) repeated-measures analysis of variance (ANOVA). There was a main effect for combination type, $F(1, 12) = 6.49, p = .03, \eta^2 = .35$, with more match than mismatch combinations occurring, overall. A Combination Type × Condition interaction was also found, $F(2, 24) = 8.04$, $p < .01$, $\eta^2 = .40$. The change in match combinations was significantly greater than the change in mismatch combinations in both the SHP ($p = .02$, two-tailed) and the FNC ($p < .02$, two-tailed) conditions but not in the CTL condition ($p = .02$, two-tailed). The increase in match combinations for the SHP ($p = .01$, one-tailed) and FNC ($p = .01$, one-tailed) conditions were greater than that of the CTL condition but did not differ significantly from one another ($p = .99$, two-tailed). Decline in mismatches was comparable in the SHP and FNC conditions ($p = .99$, two-tailed), but only the FNC condition was statistically different from the CTL condition ($p = .02$, one-tailed). A small but noticeable decline in match combinations occurred in the CTL condition. In summary, toddlers demonstrated a transition from mismatch to match combinations (i.e., a decline and increase, respectively) in the experimental conditions but not in the CTL condition.

Table 4. Frequency of gesture–speech combinations.

	SHP condition		FNC condition		CTL condition	
Combination	Visit 2	Visit 4	Visit 2	Visit 4	Visit 2	Visit 4
Mismatch	5	1	7	0	2	3
Match	1	10	2	10	5	3

Table 5. Mean gain scores (and standard deviations) for gesture–speech mismatch and match combinations.

Combination	SHP condition	FNC condition	CTL condition
Mismatch	−.31 (0.75)	−.54 (0.78)	.08 (0.49)
Match	.69 (1.03)	.62 (1.12)	−.15 (0.69)

Gesture Versus Spoken Accuracy in Mismatch Combinations: Are Functions Expressed in Gesture Before Speech?

To determine if gesture expressed accurate knowledge before speech during the transitional knowledge state, I compared the accuracy of gesture versus the spoken utterance within mismatch combinations. The data were collapsed across time and condition. This analysis used the V^2 statistic to compare the occurrence of accurate function conveyed by each modality. The V^2 *statistic* is a chi-square statistic that corrects for small frequencies. Toddlers expressed accurate information more often in the gestural (69%) than in the spoken (31%) component of mismatch combinations. This difference was reliable, $V^2 = 3.7$, $P = .05$. In summary, gesture tended to convey accurate information more than speech in the toddlers' mismatch combinations.

Discussion

The aim of this article was to demonstrate that attention to gesture as well as speech may help assess what toddlers know about the words that they are learning. This is of clinical and theoretical significance. Gesture may provide a window onto young children's mental representations at a time when oral language skills are limited and are, perhaps, an unreliable indicator of what the child knows. To accomplish this aim, I analyzed the gestures produced by the toddlers from the study conducted by Capone and McGregor (2005), in which the authors varied semantic instruction between word learning conditions. Iconic gestures cued object function in the FNC condition and object shape in the SHP condition, but no gesture cues were provided by the experimenter in the CTL condition. As part of that study, toddlers were probed for their knowledge of object function ("What do we do with this one?") at Visit 2 after they had one exposure to the objects and again at Visit 4 after they had three exposures to the objects.

In Capone & McGregor (2005), we claimed that semantic knowledge falls along a continuum of weak to progressively enriched representations and that richness of semantic representation influences word retrieval. We placed the children in a transitional knowledge state by introducing novel word-referent pairs. We manipulated semantic enrichment by providing semantic cues in the experimental conditions but not in the CTL condition. We made our case by showing that toddlers learned the same number of words under all learning conditions but that the quality of learning differed. Toddlers retrieved more words for picture naming (uncued, cued) and had richer knowledge of objects under conditions that provided semantic enrichment (SHP, FNC) than under the CTL condition. Conversely, toddlers' learning of CTL words was evident only within the task that provided the most scaffolding. These data allowed me to predict changes in the gesture–speech combinations that toddlers produced under each condition. In the current study, I first described the full repertoire of responses provided by the toddlers. Second, I analyzed the relationship between gesture and speech within their cross-modal combinations. Because Capone and McGregor experimentally controlled word learning conditions, I was able to observe the learners as they progressed from an incomplete semantic representation to a richer representation of the words that they were learning.

A high proportion of toddlers used gesture to communicate. Consistent with previous studies, participants produced gesture and speech in combination, but toddlers produced more gestures in isolation than reported for older children. There was also a higher occurrence of iconic gestures (vs. deictic) than previously reported for this age range (see Table 3). I attributed this to methodological differences between the current study and previous work. Previous work predominately examined toddlers' spontaneous gestures (Capirci et al., 1996; Iverson & Goldin-Meadow, 2005; Özçalişkan & Goldin-Meadow, 2005). The object function probe administered in this study was conducive to iconic gesturing because actions (vs. locations or naming) were probed. It is also possible that children were encouraged to increase their own use of iconic gestures because they were exposed to a high rate of iconic gestures by the experimenter (3 gestures × 3 objects × 3 visits = 27 gesture exposures). The infants studied by Goodwyn, Acredolo, and Brown (2000) gestured more often when parents were trained to increase their gestural input than when they were trained to increase their spoken input (see also McGregor & Capone, 2004). Cook and Goldin-Meadow (2006) also observed more gestures in school-age children when teachers gestured than when instruction did not include gesture.

Gesture Taps Semantic Representation

To be credited with an accurate response, toddlers' gestures had to express knowledge that was unique to the function of each object. I first argue that the toddlers' gestures were valid expressions of their knowledge. The experimenter never labeled the functions in any condition and provided gesture cues to object function only in the FNC condition. However, even in the FNC condition, only 31% of toddlers' gestures were similar to the experimenter's models. For example, the experimenter used a fisted hand to pantomime holding the /kɑs/ while demonstrating a scooping action. The gestures modeled by the experimenter have been described as *imaginary object (IO) gestures* (Boyatzis & Watson, 1993; O'Reilly, 1995). IO gestures pantomime holding an object with a fisted hand while producing its action. In contrast, toddlers used gestures that are described as *body-part-as-object (BPO) gestures,* which use a body part to represent the object while producing the action. For example, toddlers cupped a hand to represent the /kɑs/ while producing the scooping action. Therefore, the function gestures that toddlers produced were self generated and were not delayed imitations of the experimenter's models (see also the *Embodied Knowledge as a Source of Gesture* section).

Capone and McGregor (2005) reported that toddlers stated more functions under experimental conditions than under the CTL condition at the study's end; these were spoken functions only. These data were evidence of enriched semantic representations under experimental conditions. However, if semantic representations are gradually enriched over time, then object functions in the CTL condition were not necessarily missing but were, perhaps, more weakly represented. The analysis of object function in Capone and McGregor did not reflect weak semantic representations because it was a spoken production task, a task that would be supported by rich semantic representations (see Capone & McGregor for a discussion of production task demands). In the current study, an analysis of accurate gestures at Visit 4 revealed that toddlers gestured accurate functions comparably between conditions. Thus, it appears that the mental representations of objects were still evolving under all conditions, including the CTL condition. The toddlers' gestures reflected that knowledge. These data provide further evidence that weak semantic representations, not missing representations, were at the root of naming failures in Capone and McGregor.

The current study examined whether toddlers' gesture–speech combinations reflected the transition from the weak to enriched word learning observed in the experimental conditions of Capone and McGregor (2005). As with older children (e.g., Alibali & Goldin-Meadow, 1993; Church & Goldin-Meadow, 1986; Pine et al., 2004), toddlers produced gesture–speech combinations that expressed mismatching information as well as matching information, and toddlers progressed from mismatch combinations to match combinations more often when semantic instruction was provided than when no semantic instruction was provided. Consistent with Alibali & Goldin-Meadow (1993), under the CTL condition a small but noticeable regression occurred in gesture–speech match combinations when no semantic instruction was provided. The current study extends the extant literature by demonstrating that toddlers produce gesture and speech in combination and that their gesture–speech combinations reflect their word learning state.

The Function of Gesture

Acredolo and Goodwyn (1988) suggest that infant-toddlers use gestures to compensate for limitations in developing articulatory and phonological systems. It may be that, at this time, the manual development needed for gesture production is more advanced than the articulatory development needed for speech because of the "well-practiced" movements of object exploration (Iverson & Thelen, 1999, p. 34). Further, gestures provide a visual representation without the demand of formulating and encoding the verbal description (Goldin-Meadow, 2003). Speech places greater demands on memory when compared with gesture because it is encoded sequentially, whereas gesture expresses a visual representation holistically. Gesture may be an efficient means of communicating knowledge or it may facilitate the retrieval of verbal information while a representation is still evolving and weak (Goldin-Meadow & Wagner, 2005).

The act of gesturing may do more than reflect the child's state of knowledge; it may directly affect that knowledge. Alibali and Goldin-Meadow (1993) found that children who gestured were more likely to generalize trained knowledge to untrained exemplars than were children who did not gesture (see also Cook & Goldin-Meadow, 2006). Thus, the act of gesturing may facilitate the child's transition to a richer mental representation. There is preliminary evidence suggesting that the act of gesturing frees neural resources for other cognitive processes by externalizing a visual representation or by drawing attention to important aspects of a problem (Alibali & DiRusso, 1999; Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001). The discussion that follows addresses how one's own gesture may influence the development of semantic representations and be an expression of that knowledge.

Embodied Knowledge as a Source of Gesture

Gesture and language are subserved by the same neural regions of the brain. For example, motor control areas of the brain are activated during language tasks that do not involve speech, and there are patterns of coactivation in the brain between neural control areas for the hand and the mouth (for a review, see Iverson & Thelen, 1999). In other words, when language is called upon, motor control areas for both speech and gesture are readied for expression. From an associationistic perspective, both lexical and semantic information are represented within a distributed neural network that derives from multisensory experiences (e.g., Barsalou, 1999a; Barsalou et al., 2003). More specifically, sensory neurons activate during an initial exposure to a word and its referent, and association areas integrate that experience into something meaningful; the pattern of activation is stored for long-term memory. These same neural areas reactivate during subsequent experiences to enrich the representation. With regard to object representations, in particular, gesture may tap visual and/or proprioceptive sensory memories of an object experience.

In the current study, visual input came in the form of the experimenter's demonstration of object function and, in the FNC condition, gesture cues provided additional visual input. Because the child enacted the object function, this also provided a proprioceptive experience. All learning conditions shared enactment of object functions by the toddlers and visual demonstration by the experimenter. Comparisons among the SHP, FNC, and CTL conditions showed no difference in toddlers' use of gesture under each condition. Both proprioceptive and visual input most likely enriched semantic representations under all conditions, although the relative contribution of one modality over another could not be determined.

Evidence presented here showed that gesture can be both a source of semantic knowledge and an expression of that knowledge. For example, learning differences between conditions were reflected in the toddlers' use of gesture and speech in combination—that is, toddlers progressed from gesture–speech mismatch to match combinations in the SHP and FNC conditions, in which visual cues were provided to object shape and function, respectively. Therefore, gesture was a source of semantic information and, when combined with speech, reflected the richness of the semantic representation. Chaigneau and Barsalou (in press) argue that object representations are a relational system among word, object parts, and object function. For example, only when the relationship between object shape and function is transparent do children consider an object's function in their extensions of words (i.e., from labeling an original referent to labeling a novel exemplar). Perhaps the gesture cues provided by Capone and McGregor (2005) not only enriched shape and/or function nodes but also strengthened connections within the lexical–semantic representation to promote a richer, relational system among word, object parts, and function. This was expressed as richer semantic knowledge as well as less scaffolded word retrieval.

Caveats

There are two caveats to the current discussion. First, not all children gestured, and, for those who did gesture, not all children produced gesture–speech combinations. Second, the current sample of toddlers came from a restricted population (i.e., monolingual English, highly educated mothers). These issues bear on the extent to which the results can be generalized to all speakers within and across cultural, language, and economic groups. I address each issue in turn.

Although this and other studies report that the majority of children gesture, not all children gesture when explaining their solutions to tasks. Small numbers of children are classified as nongesturers. For example, Church (1999) classified 1 of 86 participants as a nongesturer; Church and Goldin-Meadow (1986) classified 1 of their 28 participants; Goldin-Meadow, Nusbaum, and colleagues (1993) classified 2 of their 17 participants; and Pine et al. (2004) classified 3 of their 99 participants. Here, 1 of 18 children did not gesture. One must then question whether or not gesturing is necessary for learning. Alibali and Goldin-Meadow (1993) actively recruited a group of nongesturers ($n = 27$). Nongesturers learned with instruction, but they tended to perform less well on posttraining tests than did gesturers. Even within an individual, the relationship between gesture and speech may not be observed consistently. Perry et al. (1988) reported that approximately one third of their participants produced gesture–speech mismatches while explaining mathematical equivalence or while explaining conservation but not while explaining both. This pattern was attributed to the child's learning state relative to each task and did not appear to be a style of communication. McGregor and Capone (2004) provided suggestive evidence that genetics may play a role in how gesture is used. This was a rare case study of trizygotic quadruplets, two identical and two fraternal genetic siblings. Children were studied from their prelinguistic period through the 50-word spurt. As part of that study, we trained a vocabulary set using gesture–speech models. All siblings showed an initial preference for gesture expression and an eventual transition to predominately spoken utterances. However, the identical genetic siblings relied on gesture–speech combinations during the 50-word spurt, whereas their fraternal siblings did not.

Gesture does not appear to be a requisite for learning (Alibali & Goldin-Meadow, 1993; Goldin-Meadow, Alibali, & Church, 1993). However, when a child does gesture, it can provide a window onto his or her stage of learning. It can also direct the adult as to the best ways of tailoring input for that child. I have suggested here that this may be particularly important for children who are limited in spoken expression. Research that examines whether nongesturers exhibit other behaviors to reflect their learning state may be a fruitful area of comparison (e.g., imitation, verbal rehearsal).

The extent to which the current findings apply to speakers from a variety of demographics can also be questioned, given the sample studied here. Regardless of culture, language, or socioeconomic class, individuals gesture while they speak (e.g., for a review, see Goldin-Meadow, 2003; Rowe, 2000). For example, cross-linguistic studies show that speakers produce gestures that convey the semantic aspects of the speech that they accompany. Findings from individuals with sensory impairments suggest that gesture production is not a cultural phenomenon. Gesturing appears to be inherent to the act of speaking (e.g., Goldin-Meadow, Butcher, Mylander, & Dodge, 1994; Iverson & Goldin-Meadow, 2001). For example, blind speakers gesture to blind listeners, and deaf children create their own gestures to communicate in the absence of spoken or gestured models. Therefore, regardless of an individual's cultural, linguistic, or socioeconomic background, individuals gesture, and their gesture conveys semantic knowledge. To my knowledge, there has been no study of how a child's gesture–speech combinations change with learning or instruction as a function of these demographic variables. This issue is also a fruitful area for continued research.

Clinical Implications

In addition to words, gesture may reveal the child's evolving word knowledge. It may be particularly important at a time in development when children are limited in articulation, language, and metalinguistic skills. It is also reported that toddlers with early expressive vocabulary delays and children with specific language impairment—two populations that demonstrate limited language abilities—use gestures to communicate what they know (Evans et al., 2001; Thal & Tobias, 1992). Although children with language impairments were not included in this study, one can speculate that attention to any child's gesture may influence the word learning environment. Adults need to be aware that gesture represents a valid mode of communication. If a child gestures, the adult can expand that communication with a gesture–speech model. For example, if the child points to an object, the adult can respond by labeling the object and producing an iconic gesture that highlights the shape or function of that object. Here, the adult would model the spoken language as well as provide semantic enrichment. Ellis Weismer and Hesketh (1993) reported that children with specific language impairment benefited in learning location words if an iconic gesture–speech model was provided during instruction than when no gesture was used. The child's iconic gestures also provide the adult with an opportunity to model spoken language for mapped concepts. If adults are aware that a child has some information represented, as indicated by the child's gesture, the adult can model the word that labels that information. Modeling spoken language for children with difficulty learning language is also supported empirically (e.g., Proctor-Williams, Fey, & Loeb, 2001; Yoder, Spruytenburg, Edwards, & Davies, 1995).

Currently, the use of gestured input with language-impaired children is considered best clinical practice within the field of speech-language pathology (German, 1992; Linder, 1993; Manolson, 1992). Here, the high rate of gesturing by the experimenter encouraged typically developing toddlers to exploit the manual modality for communication. If this relationship between gesture input and gesture production can be documented in children with language impairments, then the use of gesture in clinical practice may be validated. This awaits empirical support.

Acknowledgments

I thank Karla McGregor and Susan Goldin-Meadow for their contributions to project development and data analysis and Caseyanne Higgins for careful reliability coding. Gratitude is also extended to Kristy Grohne-Riley and Li Sheng for comments on an earlier version of this article.

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Received January 31, 2006

Revision received August 3, 2006

Accepted August 22, 2006

DOI: 10.1044/1092-4388(2007/051)

Contact author: Nina C. Capone, Department of Speech-Language Pathology, School of Graduate Medical Education, Seton Hall University, 400 South Orange Avenue, Alfieri Hall, Room 33, South Orange, NJ 07079. E-mail: caponeni@shu.edu.

Appendix. Coding decision tree for the object function probes.

I. Is there a spoken response?
  If no: No code and go to II.
  If yes: Does it contain a verb?
    If no: Does it share a thematic or locative relationship, or is it the word *label*?
      If no: Then irrelevant utterance with no code, and go to II.
      If yes: Code (V–) and go to II.
    If yes: Does the spoken response accurately depict the function?
      If no: Code (V–) and go to II.
      If yes: Code (V+) and go to II.

II. Is there a gestured response?
  If no: No code for absence of gesture and random hand movements.
  If yes: Does it accurately depict the function?
    If no: Code (G–).
    If yes: Code (G+).

Example 1: /daɪn/ = "mix it" + two palms facing each other, turning in opposite directions
  Is there a spoken response? Yes.
  Does it contain a verb? Yes.
  Does it accurately depict the function? Yes, code (V+).
  Is there a gestured response? Yes.
  Does it accurately depict the function? Yes, code (G+).
  Final code: G+V+ match.
Example 2: /paʊm/ = "pop-pop-pop" + two flat hands push downward on the table
  Is there a spoken response? Yes.
  Does it contain a verb? Yes.
  Does it accurately depict the function? No, code (V–).
  Is there a gestured response? Yes.
  Does it accurately depict the function? Yes, code (G+).
  Final code: G+V– mismatch
Example 3: /daɪn/ = "you … smush it" + point to the table
  Is there a spoken response? Yes.
  Does it contain a verb? Yes.
  Does it accurately depict the function? Yes, code (V+).
  Is there a gestured response? Yes.
  Does it accurately depict the function? No, code (G–).
Final code: G–V+ mismatch.