Cognitive Development, 14, 37–56 (1999)
ISSN 0885-2014

THE FUNCTION OF GESTURE IN LEARNING TO COUNT: MORE THAN KEEPING TRACK

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Preschoolers count objects most accurately when they gesture as they count. This study tests two possible explanations for this effect. One is that gesture helps children keep track of counted items. Another is that gesture helps children coordinate saying the number words and tagging the items. Twenty preschoolers counted chips under three types of conditions: with gesture prohibited, with active gesture, and with a puppet gesturing as children counted aloud. The puppet conditions were intended to distinguish the benefits of keeping track with gesture from the benefits of active gesture. Children counted more accurately when they or the puppet gestured than when gesture was prohibited. However, children's errors differed when they and the puppet gestured. When children gestured themselves, they made errors keeping track, but when the puppet gestured, they made errors coordinating number words and items. Thus, active gesture helps children both to keep track and to coordinate tagging the items and saying the number words. In these ways, active gesture helps children implement their knowledge of one-to-one correspondence.

This paper is based on an undergraduate Honors Project conducted by Alyssa DiRusso under the direction of Martha Alibali. The research was supported by a grant from the Undergraduate Research Initiative at Carnegie Mellon University. We thank Michael Perrott, Audrey Russo, and Anindita Basu for assistance in coding and establishing reliability, and Theresa Graham, Philip Garber, Lisa Haverty, Spencer Kelly, and Bethany Rittle-Johnson for helpful discussions and for comments on previous versions of the manuscript. We are especially grateful to Sharon Carver, Jean Veltri, and the teachers and students at the Carnegie Mellon University Children's School, who made this work possible. A preliminary report of this work was presented at the 1996 Meeting of the Midwestern Psychological Association. Alyssa A. DiRusso's present address: the University of Texas, Austin, School of Law.

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Manuscript received December 16, 1996; revision accepted May 4, 1998

Counting is a foundational skill in early mathematics, and one that takes children several years to master. The present study investigates a type of action that is ubiquitous in counting, and that may actually contribute to the development of counting skill: spontaneous gesture. Pointing and touching gestures are often used spontaneously by children and adults to "tag," or assign numerical meaning, to counted objects. The goal of the present study is to examine the role of such indicating gestures in children's counting performance.

There is a large body of evidence that pointing and touching gestures facilitate counting accuracy, both in children (Fuson & Hall, 1983; Gelman & Meck, 1983; Saxe & Kaplan, 1981; Shaeffer, Eggleston, & Scott, 1974) and in nonhuman primates, such as chimpanzees (Boyson, Berntson, Shreyer, & Hannan, 1995). The link between gesture and counting accuracy is strongest during children's preschool years, as Saxe and Kaplan (1981) have shown. In a cross-sectional study, they compared the counting performance of 2-, 4- and 6-year-old children under both a gesture-allowed and a gesture-prohibited condition. At age 2, children were rarely accurate in their counts, and they were aided little by the opportunity to gesture. By age 6, children were consistently accurate (near ceiling) in their counts, and gesturing again had little impact on accuracy. However, at age 4, children counted accurately more often when they were allowed to gesture than when they were prohibited from gesturing. Thus, gestures appear to be most beneficial for children when they are learning to count, before they become proficient counters.

Saxe and Kaplan (1981) did not distinguish between pointing gestures and touching gestures in their study. However, there is some evidence that touching gestures are more effective at facilitating counting accuracy than pointing gestures that do not contact the counted items. Gelman and Meck (1983) constructed a Plexiglas cover that could be placed over a set of objects, so they could be seen and pointed to, but not touched. They found that 3- and 4-year-old children counted less accurately when objects were covered than when they were uncovered. Thus, the available data suggest that although both pointing and touching are associated with accurate counting in preschoolers, touching gestures are most effective.

In the present study, we examine *why* such touching and pointing gestures facilitate counting accuracy in preschool children. Graham (1993, 1998) has suggested that gesture may help children to map the number words to the counted objects. In line with this view, we hypothesize that gestures help children to implement their knowledge of one of the fundamental counting principles: one-to-one correspondence.

One-to-one correspondence is the principle that each counted item must be assigned a unique number word (Gelman & Gallistel, 1978). Children demonstrate a conceptual understanding of this principle by age 4 (Briars & Siegler, 1984; Frye, Braisby, Love, Maroudas, & Nicholls, 1989; Gelman & Meck, 1983). For example, in one study (Gelman & Meck, 1983), 4-year-old children judged counts produced by a puppet that adhered to the one-to-one principle to be correct, and counts that violated the principle to be incorrect. However, despite this conceptual understanding, 4-year-old children still frequently make errors in implementing the one-to-one correspondence principle in spontaneous counting (Gelman & Gallistel, 1978). That is, despite their *conceptual competence* in understanding one-to-one correspondence, 4-year-old children do not have the *procedural competence* to apply this principle consistently in counting (Greeno, Riley, & Gelman, 1984). Saxe and Kaplan's (1981) study suggests that gesture may play a role in the development of procedural competence at counting. However, their work does not specify *how* gesture contributes to procedural skill. The goal of the present study is to test two hypotheses about how active gesture contributes to procedural competence at counting.

To accurately implement the principle of one-to-one correspondence, children must do two things: (1) keep track of the objects that have been counted and those that are yet to be counted, and (2) coordinate reciting the string number words with tagging each object. We hypothesize that gesture could facilitate counting accuracy by helping children implement either or both of these components of one-to-one correspondence. That is, gesture might simply help children to keep track of counted objects. However, gesture might also help children to accurately assign a different number word to each object. That is, gesture could help children to coordinate the two activities involved in counting: reciting the string of number words, and tagging each object in some way. Note that there are many possible ways to "tag" objects in the process of counting: by looking, by moving them, by marking them in some way, by touching, or by pointing (see Greeno et al., 1984). Children may find it easier to coordinate saying the number words with *gestural* tags than with other types of tags, because children routinely use speech and gesture together in an integrated way (McNeill, 1992). Thus, gesture may facilitate counting accuracy by helping children to coordinate reciting the number words and tagging the items.

Procedural difficulties with each of these two components of one-to-one correspondence should be reflected in different types of errors in children's spontaneous counting. Indeed, Gelman and Gallistel (1978) identified two different types of one-to-one correspondence errors, which map directly onto these two components of one-to-one correspondence. *Partitioning errors* are errors in assigning items to the have-been-counted and to-be-counted groups (e.g., skipping an item, or double-counting an item), and are thus errors in keeping track. *Coordination errors* are errors in coordinating the set of number words with the action of tagging each item (e.g., continuing to say number words after the last item has been indicated, or failing to assign a number word to the last item in an array). Note that both types of errors result in a failure to maintain the one-to-one correspondence between the number of *number words* and the number of *items*.

In the present study, we tested whether gesture helped children to keep track, and whether gesture helped children to coordinate reciting the number words and tagging the objects. We tested these possibilities by comparing children's counting performance under different experimental conditions. To test whether gestures helped children to keep track of counted objects, we compared children's performance when gestures are used in counting, and when gesture is prohibited. We expected that children would count more accurately with gesture than without, replicating Saxe and Kaplan (1981).

To test whether gestures help children to coordinate reciting the number words and tagging the items, we compared children's performance when they actively gestured while saying the number words, and when a puppet gestured for them as they said the number words. The goal of the puppet conditions was to distinguish the benefits of simply keeping track with gesture from the benefits of active gesture. The puppet's gestures help keep track, because the puppet in this study did not skip items or tag items twice. However, the puppet's gestures cannot ensure that children accurately coordinate reciting the number words and tagging the items—children can go on reciting number words after the puppet tags the last item, or can fail to recite a number word for the puppet's final tag. In contrast to the puppet's gestures, children's own gestures could both help keep track of counted objects (albeit imperfectly) *and* help to coordinate reciting the number words and tagging the items (also potentially imperfectly).

To assess whether active gesture helps children coordinate reciting and tagging, we compared children's errors in conditions in which a puppet kept track, and in conditions in which children actively gestured. If gesture simply helps keep track of counted objects, then children should count more accurately when the puppet gestures for them than when they gesture themselves, because children make Partitioning errors, but the puppet does not. However, if gesture also helps children to coordinate reciting the number words and tagging the items, then children will make fewer Coordination errors when they gesture themselves, and more Coordination errors when the puppet gestures. These additional Coordination errors will "offset" the benefits of the puppet's error-free keeping track. Thus, if gesture helps children to coordinate reciting the number words and tagging the items, children should count at least as accurately when they gesture themselves as when the puppet gestures.

METHOD

Participants

Twenty-five children (14 boys and 11 girls) from a university preschool participated in the study. Children were drawn from two 4-year-old classrooms at the school. All 25 children participated in an initial testing session, as described below. Four children (three boys and one girl) did not continue in the study after this session because they accurately counted three or fewer of the 20 sets of chips used in the initial session. One boy became ill after the initial session and did not return to school during the course of the study. Thus, the final sample consisted of 20 children (10 boys, 10 girls). Participants' ages ranged from 4 years, 3 months to 5 years, 4 months (M = 4 years, 8 months).

Materials

Each child was asked to count sets of plastic chips that were pasted on strips of cardboard. Each strip was 28 inches long by 3.5 inches wide. Chips were 1 inch in diameter and were pasted approximately 1/2 inch apart. As in previous counting studies (e.g., Briars & Siegler, 1984), the chips in each set alternated in color (e.g., orange, blue, orange, blue).

The experiment used 20 sets of chips, ranging in size from 7 to 17. The sets were divided into four groups of five sets each. Each set within a group was a different size, and the mean set size in each group was 12. The four groups were rotated across experimental conditions, and the order of sets within each group remained constant. To ensure that all children left each session with a success, a fifth group of four small sets was used at the end of each session. This group included sets of 3, 4, 5, and 6 chips.

A pink pig puppet was used to point to and touch the chips during the experimental sessions on the second day of testing.

Procedure

Participants were tested individually in a laboratory room within the preschool. Children were familiar with the room and were comfortable in the surroundings. The experiment took place in two sessions of 5–10 min each. As described below, during the first session, children counted sets of chips under four conditions, and during the second session, children counted sets of chips under three conditions. The experiment was videotaped so that children's counting performance could be assessed.

Session One: Children Counting. Once the child was comfortable, the experimenter explained that she would show the child sets of chips, and ask the child to count the chips. In the first session, each child counted one group of five sets of chips under each of the following experimental conditions: (1) *no instructions*, in which no instructions regarding pointing or touching were given (and therefore children's gestures were spontaneous and natural); (2) *child point*, in which children were instructed specifically to point to (but not touch) each chip as they counted it; (3) *child touch*, in which children were instructed specifically to touch each chip as they counted it; and (4) *no gesture*, in which children were told specifically *not* to point to or touch the chips as they counted them. All children counted in the no-instructions condition first, to establish a baseline score for each child that was unaffected by experience in the other experimental conditions. Following the no-instructions condition, children counted in the remaining three conditions, with condition order randomized across children. In all conditions, if children did not count the chips in the requested manner (e.g., by touching each chip in the child-touch condition), the experimenter reminded them how they were to count on that trial, and asked them to start again.

In each condition, the experimenter demonstrated the relevant counting method before the first set was counted. In introducing the child-point condition, the experimenter pointed to the first three chips in the first set, counting "one, two, three" while pointing about 2 inches above each chip. The experimenter did not explicitly instruct the children how high above the chips to point, but most children pointed between 1/2 inch and 3 inches above each chip. In introducing the child-touch condition, the experimenter touched the first three chips in the first set, counting "one, two, three" while touching each chip. In introducing the no-gesture condition, the experimenter instructed children to clasp their hands together and keep them on the table, without moving them, as they counted the chips out loud. The experimenter demonstrated for the children how to clasp hands.

After children counted chips under all four conditions, the experimenter told them that there were still a few sets left, and that they could count them however they wanted—by pointing, by touching, or neither. For this part of the session, the group of strips with small sets was used, so that all children would conclude the session on a successful note. After counting this last group, children were accompanied back to their classroom.

Session Two: Puppet Counting. The second session was held approximately 3 days after the first session (range 1–7 days). In this session, the experimenter asked the children to count the chips with the help of a pink pig puppet. The experimenter introduced the child to the puppet and the tasks in the following way:

> This is my friend Piggy. Would you like to say hi to Piggy? Now, Piggy knows how to count, but he can't talk, so he can't say the number words like one, two, three. So what I'd like you to do is count the circles out loud while Piggy points to the circles for you. Can you do that?

During the second session, each child counted one group of five sets of chips under each of the following conditions: (1) *puppet point*, in which the puppet pointed to each chip as the child said the number words; (2) *puppet touch*, in which the puppet touched each chip as the child said the number words; and (3) *puppet incorrect*, in which the puppet made "errors" in pointing to the chips as the child said the number words (see below). The order of the puppet-point and puppet-touch conditions was randomized across children. The puppet-incorrect condition was always presented last, so that children's belief that the puppet was tagging the items correctly would not be questioned until data had been gathered in the other two conditions. Children were asked to keep their hands clasped on the table during all of the puppet counting conditions. In introducing the puppet conditions, the experimenter demonstrated how to clasp hands, as she had in the no-gesture condition in the first session.

In all of the puppet conditions, the experimenter controlled the puppet's pointing or touching with her finger inside the puppet's left front foot. In the puppet-point condition, the puppet pointed approximately 2 inches above each chip, as the child said the number words. In the puppet-touch condition, the puppet touched each chip with its foot as the child said the number words. In the puppet-incorrect condition, the puppet pointed to the chips with its foot as the child said the number words, but the puppet made errors in the one-to-one correspondence between *gestures* and *chips*. The puppet skipped (i.e., did not point to) one chip on two of the five sets, and pointed to one chip twice on three of the five sets. Thus, for every set in the puppet-incorrect condition, the number of indicating gestures produced by the puppet was either one too few or one too many. The purpose of this condition was to ensure that children were paying attention to the puppet, rather than counting the chips independently.

In all of the puppet conditions, the children set the pace of the count, and the experimenter-controlled puppet indicated the chips in synchrony with the children's verbal counting. Since children tended to count rhythmically, this procedure posed no difficulties for the experimenter. Thus, in all the puppet conditions (including the puppet-incorrect condition), the one-to-one correspondence between the child's *words* and the puppet's *gestures* was implemented accurately. The puppet started when the children were ready to begin. If children paused in the counting string during the set (which occurred rarely), the puppet waited for children to continue. If children failed to say a number word for the last chip in the set, the puppet waited briefly at the last chip, and then retracted its foot.

After the three puppet conditions were completed, the experimenter told the children that there were still a few sets left, and that they could choose how to count them—either by themselves, or with Piggy helping. As in Session One, for this part of the session, the group of small sets was used, so that all children would conclude the experiment on a successful note. After counting this last group, children were given the opportunity to play with the pig for a few minutes if they desired. They were then thanked for their participation, and they were accompanied back to their classroom.

Coding

Coding Children's Counting Performance as Correct or Incorrect. For each set, children's counting performance was assessed as either correct or incorrect. There were two criteria for correct performance: (1) the child assigned one and only one number word to each chip, and (2) the child used the count words in the conventional order, or in an unconventional order that was used consistently across sets, and that included no repeated number words.[1] Any deviation from

[1] Two children used the count words in an unconventional order but used that order consistently across trials. One of these children always skipped the number "13," and the other always skipped the number "15." Throughout this paper, these trials were counted as correct. The pattern of results does not change if these trials are counted as incorrect.

correct performance was considered incorrect. Note that this definition of correct performance requires only that there be a perfect one-to-one correspondence between the number of *count words* and the number of *chips*. In conditions in which children gestured, trials were scored as correct as long as they met this criterion, even if there was not a perfect one-to-one correspondence between the number of *gestures* and the number of *chips* or between the number of *gestures* and the number of *count words*. Put another way, correct performance did not require "correct" gestures in the conditions in which children were allowed or required to gesture.

Coding Types of Errors. In four of the experimental conditions (puppet point, puppet touch, child point, and child touch), children's counting errors were assessed on all trials on which they counted incorrectly. We identified six different types of errors in children's counting performance (see Table 1). We grouped these errors into three categories (the first two of which were defined by Gelman & Gallistel, 1978, p. 89 ff.): (1) *Partitioning errors*, which are errors in assigning items to the have-been-counted and yet-to-be-counted groups (Skip and Double count), and which are therefore errors in keeping track, (2) *Coordination errors*, which are errors in coordinating the set of number words with the action of tagging each item (Stop short and Continue), and (3) *Other errors*, which were errors that could not be classified as either Partitioning or Coordination errors (String error and Distracted). Trials sometimes included more than one type of error (e.g., Skip and String error). Note that both Partitioning errors and Coordination errors are errors in the one-to-one correspondence between number words and objects.

Table 1. Coding Categories for Children's Counting Performance

Code	Definition
Correct	The child assigns one number word to each chip, and uses the count words in the conventional order (or in an unconventional order that is used consistently across trials).
Partitioning Errors	
Skip	The child does not assign a number word to a chip.[a]
Double count	The child assigns two or more number words to a particular chip.[a]
Coordination Errors	
Continue	The child continues to say number words after the last chip has been indicated.
Stop short	The child does not assign a number word to the last chip (or last few chips) to be counted.
Other Errors	
String error	The child uses the set of number words in an incorrect order that is used inconsistently across trials.
Distracted	The child is distracted from counting.

Note. [a]Skips or double counts of the *last* chip in an array were counted as coordination errors (Stop short or Continue).

Reliability

To establish reliability in coding children's performance as correct or incorrect, two different coders scored all 700 trials as either correct or incorrect. Agreement between two coders was 95%. To establish reliability in coding types of counting errors, all incorrect trials in the child-point, child-touch, puppet-point, and puppet-touch conditions were also coded by a second coder. Agreement between two coders for identifying and classifying errors was 82%.

RESULTS

To prepare the data for analysis, the number of sets that each child counted correctly under each condition was scored. The highest possible score under each condition was 5. Unless otherwise noted, all statistical tests reported were significant at $p < .01$.

We first examined whether children were indeed paying attention to the puppet in the puppet conditions. If children were paying attention to the puppet, they should make many counting errors in the puppet-incorrect condition, in which the puppet made indicating errors on each trial (i.e., skipping a chip or indicating a chip twice). We compared children's performance in the puppet-incorrect condition with their performance when they counted independently (in the no-instructions condition). As expected, children counted the chips correctly much less often in the puppet-incorrect condition than in the no-instructions condition ($M = 1.10$ vs. $M = 4.05$, paired $t(19) = 10.33$).[2]

We then used repeated measures analysis of variance (ANOVA) to compare children's performance in the remaining five conditions (no gesture, child point, child touch, puppet point, and puppet touch). The analysis revealed a significant main effect of condition, $F(4, 76) = 19.87$. Planned comparisons were used to test specific hypotheses, as described in the following sections.

Does Gesturing to the Counted Items Facilitate Counting Accuracy?

Based on findings reported by other investigators (Gelman & Meck, 1983; Saxe & Kaplan, 1981; Shaeffer et al., 1974; Van Devender, 1986), we expected

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[2] Indeed, in the puppet-incorrect condition, the number of count words that children produced coincided exactly with the number of indicating gestures made by the puppet on slightly more than half of the trials (on average, 2.75 of 5 trials). Further, when there were discrepancies, children's counts were as likely to be incorrect as to be correct. Children sometimes compensated for the puppet's errors (e.g., by saying an extra number word after the puppet's last indication, on a trial in which the puppet had skipped an item, yielding a correct count; $M = 1.15$ trials); however, they just as often failed to compensate for the puppet's errors (e.g., by saying an extra number word after the puppet's last indication, on a trial in which the puppet had indicated one item twice, leading to a count that was two counts over the correct count; $M = 1.10$ trials). These results suggest that children were in fact paying attention to the puppet, rather than counting the chips independently.

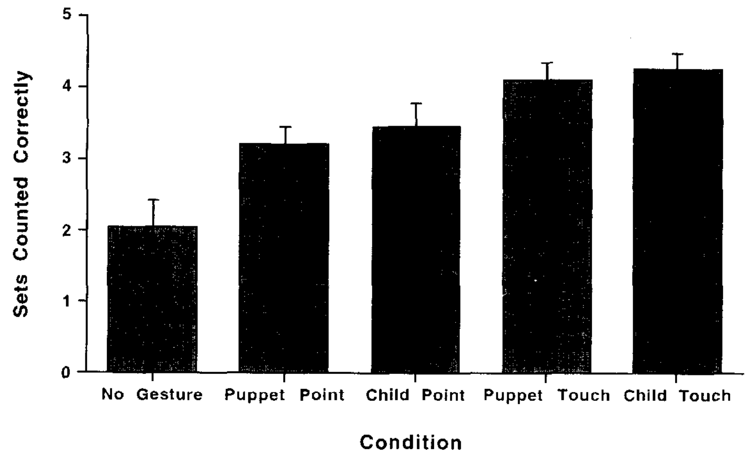

Figure 1. Mean number of sets counted correctly (out of 5 possible) in each experimental condition. The error bars represent standard errors.

that children's counting accuracy would be poorest when they were prohibited from gesturing to the chips. This prediction was confirmed in planned contrasts that compared children's performance in the no-gesture condition to their performance in the puppet conditions (i.e., no gesture vs. puppet point and puppet touch combined, $F[1, 76] = 44.07$) and in the child conditions (i.e., no gesture vs. child point and child touch combined, $F[1, 76] = 55.78$). As seen in Figure 1, performance in the no-gesture condition was substantially lower than performance in each of the other conditions. Thus, children's own gestures facilitated accuracy, but so did the puppet's gestures, which simply kept track of the counted items. These findings support the claim that gesture promotes accurate counting by helping to keep track of counted items.

We next considered whether the effects of experimental condition depended

Table 2. Mean Number of Sets Counted Correctly for the Two Smaller Sets (10 and Under) and the Two Largest Sets (13 and over) in each Condition

Condition	Small Sets	Large Sets
Puppet point	1.55 (0.51)	1.20 (0.77)
Child point	1.65 (0.59)	1.20 (0.89)
Puppet touch	1.75 (0.55)	1.50 (0.76)
Child touch	1.90 (0.31)	1.55 (0.69)
No gesture	1.00 (0.86)	0.60 (0.68)
No instructions	1.80 (0.41)	1.45 (0.83)
Puppet incorrect	0.45 (0.69)	0.45 (0.61)

Note. The maximum score in each category is 2. Numbers in parentheses are standard deviations.

on the size of the sets that children counted. That is, we examined whether the effects of condition held for both large and small sets. To do so, we compared children's performance on the two smallest sets and the two largest sets presented in each condition.[3] The results are presented in Table 2. Not surprisingly, children counted more accurately on small sets than they did on large sets, $F(1, 19) = 7.36$, $p < .02$. However, there was no interaction of set size and experimental condition, $F(6, 114) = 0.75$, $p = .61$. As seen in Table 2, for both small and large sets, performance in the no-gesture condition was substantially lower than performance in the child conditions (child point and child touch) and in the puppet conditions (puppet point and puppet touch).

We next compared children's performance when they (or the puppet) touched each item with their performance when they (or the puppet) pointed to each item. Like Gelman and Meck (1983), we found that children counted more accurately when they touched each chip than when they pointed to each chip, $F(1, 76) = 8.26$. Surprisingly, however, we also found that children also counted more accurately when the *puppet* touched each chip than when the puppet pointed to each chip, $F(1, 76) = 10.45$. Moreover, this pattern held for both small and large sets (see Table 2). These findings suggest that the key difference between touching and pointing is not the tactile information provided by the touch, but rather the distance between the indicating act and the object indicated. We consider the implications of this finding in the Discussion.

Do Children Count More Accurately When They Gesture or When the Puppet Gestures?

As noted above, despite evidence that 4-year-olds understand one-to-one correspondence (Briars & Siegler, 1984; Gelman & Meck, 1983), they frequently make errors in implementing this understanding (see, e.g., Gelman & Gallistel, 1978; Graham, 1998). We hypothesized that, if counting gestures serve simply to keep track of the counted items, then children should make *more* errors in the conditions in which they gestured themselves (the child-point and child-touch conditions) than in the conditions in which the puppet gestured for them (the puppet-point and puppet-touch conditions), because they would make errors in keeping track, and the puppet would not. In contrast, if gesture does more than simply keep track, the "gains" of children's active involvement in gesturing would offset the "losses" due to their errors in keeping track. In this case, children should make a comparable number or fewer errors when they gesture themselves as when the puppet gestures for them.

Thus, for our interests, the critical test compared children's performance in the conditions in which they actively gestured to their performance in the conditions

[3] Recall that there were four groups of five sets each, which were rotated across conditions in the experiment. In every group, the two smallest sets were between 7 and 10, and the two largest sets were between 13 and 17.

in which the puppet gestured for them. That is, the critical test compared the effects of gesturer (child vs. puppet). If gestures simply keep track of counted items, children's performance should be significantly higher in the puppet conditions. In contrast, if gestures do more than keep track, children's performance either should not differ in the child and the puppet conditions, or should be higher in the child conditions.

A planned contrast showed that children's performance did not differ statistically in the puppet conditions and the child conditions, $F(1, 76) = 1.03, p = .31$. Children's performance was actually slightly *better* when they gestured themselves than when the puppet gestured for them. As seen in Figure 1, children counted slightly more accurately in the child-touch condition than in the puppet-touch condition (Ms = 4.25 vs. 4.10), and also counted slightly more accurately in the child-point condition than in the puppet-point condition (Ms = 3.45 vs. 3.20). Moreover, this pattern held for both small and large sets (see Table 2). These findings are especially striking since the puppet never made errors in keeping track, and the children often did (see below). These results are evidence that children's gestures do more than simply keep track of the counted objects.

Because the puppet never made errors in keeping track, this pattern of results implies that children must have made other types of errors in the puppet conditions, errors that offset the benefits of the puppet's accurate keeping track. We turn next to an analysis of children's errors.

What Errors Do Children Make When They Gesture and When the Puppet Gestures?

As described above, we identified six different types of errors in children's counting performance (see Table 1). These included two types of Partitioning er-

Table 3. Errors made in Child Conditions (Child Touch and Child Point) and Puppet Conditions (Puppet Touch and Puppet Point)

	Percent of Trials with Error Made		Percent of Children who Made Error	
	Child Conditions (N = 200)	Puppet Conditions (N = 200)	Child Conditions (N = 20)	Puppet Conditions (N = 20)
Partitioning Errors				
Skip	14.0%	NA	60%	NA
Double count	7.5%	NA	45%	NA
Coordination Errors				
Continue	0.5%	19.5%	5%	80%
Stop short	1.5%	2.5%	15%	25%
Other Errors				
String error	5.5%	9.0%	30%	30%
Distracted	0.5%	0.0%	5%	0%

Note. NA = not applicable.

rors, which are errors in keeping track (Skip and Double count), two types of Coordination errors, which are errors in the coordination of number words and object tags (Continue and Stop short), and two types of errors that were neither Partitioning nor Coordination errors (String error and Distracted).

Some of these error types were not possible when the puppet gestured to the items. Children could not skip an item or double count an item when the puppet gestured for them (except in the puppet-incorrect condition, in which the puppet skipped items or double-tagged items on every trial). However, when the puppet gestured to the items, children continued to make other types of errors, sometimes using an incorrect set of number words (String error), sometimes continuing to say number words after the puppet had tagged all the items (Continue), and sometimes failing to say a number word when the puppet tagged the last item (Stop short).

Table 3 presents the frequency of errors of each type in the child conditions (child touch and child point) and in the puppet conditions (puppet touch and puppet point). We found that children made substantially more Coordination errors (Continue and Stop short) in the puppet conditions than they did in the child conditions. As shown in Figure 2, on average, children made 2.20 Coordination errors in the puppet conditions, and only 0.20 Coordination errors in the child conditions (paired $t[19] = 6.89$). These data indicate that children's active gestures help them to coordinate the two actions that make up counting: reciting the number words and tagging each of the items.

The prevalence of Coordination errors in the puppet conditions also holds on an individual level within the pointing conditions and within the touching conditions. In a comparison of the puppet-point and child-point conditions, all 16 of

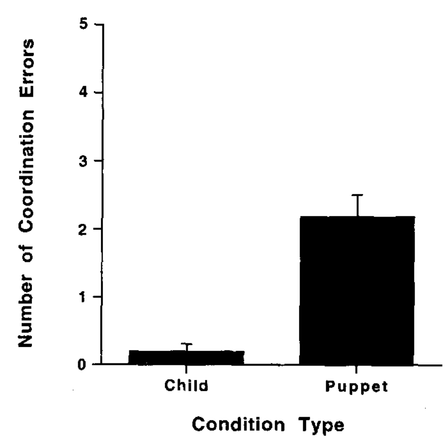

Figure 2. Mean number of coordination errors (out of 10 possible) in the child conditions (child point and child touch) and in the puppet conditions (puppet point and puppet touch). The error bars represent standard errors.

the children who showed a difference in the number of Coordination errors across the two conditions made more Coordination errors in the puppet-point condition ($p < .01$, Binomial test). Similarly, in a comparison of the puppet-touch and child-touch conditions, of the eight children who showed any difference in the number of Coordination errors across the two conditions, seven made more Coordination errors in the puppet-touch condition ($p < .05$, Binomial test).

We did not expect the number of String errors to vary across conditions. To our surprise, children made more String errors in the puppet conditions than the child conditions, although the difference did not reach significance, $M = 0.90$ vs. $M = 0.55$; paired $t(19) = 1.58$, $p = .13$. Of the seven children who made String errors, five made more in the puppet conditions, and two made more in the child conditions ($p > .20$, Binomial test).

Do "Directed" Gestures or Spontaneous Gestures Lead to More Accurate Counting?

Our results indicate that active gesture helps children to implement their knowledge of one-to-one-correspondence in accurate counting procedures. We next considered whether the effects of active gesture differed when children behaved spontaneously (i.e., in the no-instructions condition) and when they were directed to gesture or not to gesture by the experimenter (i.e., in the child-touch, child-point, and no-gesture conditions).

In the no-instructions condition, when children were not given instructions about how to count, almost all of the children (18 of the 20) gestured spontaneously on every one of the five trials. Seventeen children touched the chips on every trial, and one pointed to the chips (but did not touch them) on every trial. The remaining two children counted aloud, but did not point to or touch any of the chips, on every trial. Surprisingly, every child used the same counting "strategy" across all five trials. Thus, although there was variability *across* children in the strategies used to count in the no-instructions condition, there was no variability *within* individual children.

Table 4. Mean Number of Sets Children Counted Correctly (out of 5) Using Spontaneous vs. Directed Counting Strategies

Strategy	Number of Children Using Strategy Spontaneously[a] (No-Instructions Condition)	Number of Sets Counted Correctly: Spontaneous Use (No-Instructions Condition)	Number of Sets Counted Correctly: Directed Use (Comparable "Directed" Condition)
Touch	17	4.29 (0.92)	4.17 (1.07)
Point	1	3.00 (NA)	4.00 (NA)
No gesture	2	2.00 (1.41)	2.50 (0.71)

Note. The numbers in parentheses are standard deviations. NA = not applicable.
[a]All children used the same strategy across all five trials in the no-instructions condition.

Because so many children gestured spontaneously, we were able to examine whether directed gestures or spontaneous gestures led to greater counting accuracy. The results are presented in Table 4. Because very few children used the Point and No-Gesture strategies, a statistical comparison was performed only for children who used the Touch strategy. For these 17 children, we compared their accuracy in the no-instructions condition to their accuracy in the child-touch condition. Children's performance in the two conditions did not differ statistically, paired $t(16) = 0.62, p = .54$. Thus, there was no evidence to suggest that spontaneous and directed gestures had different effects. Active gestures appear to promote accuracy, regardless of whether they are spontaneous or directed. This finding implies that, for children who do not touch objects spontaneously when counting, instructions to touch each item may lead to more accurate counting.

Discussion

In this study, children counted as accurately when they actively gestured as when a puppet gestured for them, even though the puppet did not make errors in keeping track and the children did. Our results suggest that gestures help children in two ways to implement their knowledge of one-to-one correspondence. First, gestures clearly help children to keep track of counted objects. We found that children's counting was much less accurate when they were prohibited from gesturing than when they or the puppet gestured. Second, active gestures help children to coordinate the two processes that make up counting: reciting the number words, and tagging each of the objects. We found that errors in coordinating these processes were much less frequent when children were allowed to gesture on their own. Thus, children's active gestures do more than keep track—they also help children to accurately assign the number words to the counted objects.

Depending on whether the puppet gestured or they gestured themselves, children experienced different kinds of procedural difficulties in counting, leading to different types of errors. When the puppet gestured, children made errors in coordinating the number words with the objects. When children gestured themselves, they made errors in keeping track of the counted objects. Thus, the nature of children's procedural difficulties depended on specific features of the counting situation—in particular, who does the gesturing. Our results highlight two different aspects of procedural competence at counting that are developing in preschoolers: keeping track of the counted objects and coordinating the number words with the objects. We argue that active gesture contributes to the development of procedural competence at counting by helping children to implement these two aspects of one-to-one correspondence.

What mechanism underlies the facilitating effects of counting gestures? One possibility is that active gesture makes children more attentive to the task, leading to greater accuracy. If this were the case, the increase in Coordination errors in the puppet conditions would be due to children's being less attentive in the puppet conditions than in the child conditions. At face value, we find this explanation unlikely, because children appeared to be attentive and engaged throughout the experiment, and not only during the child conditions. Indeed, at least three lines of evidence suggest that children were attentive and engaged in the puppet conditions. First, when the puppet counted incorrectly (in the puppet-incorrect condition), children almost always counted incorrectly as well. In fact, their counts most often coincided with the number of indicating acts produced by the puppet, and not with the actual number of chips. This shows that they were in fact engaged in the task and following the puppet's performance. Second, children's errors were not bizarre or extreme in the puppet conditions. When children continued to say number words after the puppet indicated the last chip, they typically continued for only one number tag. Third, children did not appear to be more distracted or less engaged in the puppet conditions, as shown by the complete absence of Distracted errors. Most children liked the puppet very much and were excited about helping the puppet count.

Nevertheless, it is possible that, even though children were attentive and engaged throughout the experiment, the focus of their attention differed in the puppet and child conditions. Indeed, it seems possible that children attend to different aspects of the counting task when they actively gesture than when they watch the puppet gesture. The discrete, beat-like motions that children produce when they gesture toward each chip may focus their attention on the discrete items being counted. Such actions, which children do not make in the puppet conditions, may help children to unitize or individuate the objects to be counted, and thereby to segment the counting task into discrete units (see Fuson, 1988, and Steffe, 1991, for discussion of this issue). This increased segmentation may in turn facilitate the accurate coordination of number words and individual items. In this way, gestures may help children to link the number words and the objects (Graham, 1993, 1998).

Further support for this idea comes from our findings on the benefits of touching versus pointing. If gestures help counters to segment the counting task, then it is not surprising that touching the chips resulted in more accurate performance than simply pointing to the chips, both in the child conditions (replicating Gelman & Meck, 1983) and in the puppet conditions. Because a touch is closer to the tagged object than a point, it is more clear which specific object is indicated by a touch than by a point. Consequently, touching the items may lead to better individuation of the items than pointing gestures. If items are more distinct, it may be easier to implement one-to-one correspondence involving the items. Thus, gesture may facilitate the implementation of one-to-one correspondence by contributing to the individuation of the items, and thereby to the segmentation of the counting task into units.

Another mechanism by which gestures may facilitate one-to-one correspondence is by providing support for working memory. Children's failure to implement their knowledge of one-to-one correspondence may be due to resource limitations, and gestures may help mitigate the effects of such limitations. Indeed, changes in working memory resources (or in how such resources are deployed) have been invoked by many researchers as an explanation for developmental differences in performance (see, e.g., Case, 1985; Case, Kurland, & Goldberg, 1982; Halford, 1993). Similarly, in other, nondevelopmental contexts, individual differences in performance can frequently be explained by individual differences in working memory capacity or in strategic use of resources (Just & Carpenter, 1992). Thus, resource limitations may be one reason why children do not consistently implement their knowledge of one-to-one correspondence in spontaneous counting.

One way to overcome such resource limitations is to represent some of the contents of working memory in the external environment (see Kirsh, 1995; Kirsh & Maglio, 1994). Gestures externalize some of the contents of working memory, so that they need not be held internally—thus, gesture can serve as an extra "memory register" when needed. Indeed, children's spontaneous gestures may actually index the amount of resource demand imposed by a task (Goldin-Meadow, Nusbaum, Garber, & Church, 1993). When tasks are more demanding, gestures may be produced to manage cognitive load.

In the case of children's counting, gesture could reduce resource demands by physically instantiating some of the contents of working memory. We propose that keeping track of counted objects and tagging each object require fewer working memory resources when done physically, with a gesture, than when done visually, by looking at each item (as in the no-gesture condition) or by looking at the puppet's gestures (in the puppet conditions). Gestures serve as an external place-holder, physically marking the child's place in the set of counted objects, so that it need not be stored in working memory. Consequently, when children tag objects with active gestures, they have more resources available for reciting the number string and for coordinating the number words with the gestural tags. Under this view, children in this study made fewer Coordination errors in the child conditions than in the puppet conditions because working memory demands were diminished when children gestured themselves.

This resource account provides a straightforward explanation for the observed increase in String errors in the puppet conditions. If gesture serves to decrease working memory demands, then children can devote more resources to reciting the string of number words when they actively gesture. This would lead to fewer String errors in the child conditions, when children actively gestured, than in the puppet conditions, when they did not. Our findings on this issue were suggestive rather than definitive; nevertheless, they are consistent with a resource explanation.

The resource account is also compatible with Fuson and Hall's suggestion that "an internalization of the pointing act [in counting] . . . seems to occur with age" (Fuson & Hall, 1983, p. 56; Fuson & Mierkiewicz, 1980). Fuson and Hall summarize previous studies showing that 3-year-old children typically touch objects when counting, whereas 4- and 5-year-old children sometimes point rather than touch (as we also found in the present study), and college students often use gaze rather than any external gesture (although it seems likely that even college students would use gesture with large sets or with objects that are difficult to individuate). These data suggest that, over development, the process of counting becomes more automatized and less resource-intensive, so that with increasing age, externalizing behavior such as gesture is no longer needed to obtain an accurate count. Among the 4-year-old children in the present study, counting was not yet well practiced or automatized, so active gestures helped them to manage resource demands.

In sum, our work demonstrates that gestures contribute to accurate counting performance. Further, our work identifies the specific aspects of performance that are facilitated by gesture, and offers explanations for why and how gesture plays a role in performance. Gestures help children to accurately implement their knowledge of one-to-one correspondence, both by helping children keep track of counted objects, and by helping children to coordinate saying the number words and tagging the objects. We have suggested two possible mechanisms that could account for these facilitating effects. First, gesture may help children to individuate the counted objects, and thereby to segment the counting task into discrete units. This increased segmentation may make it easier to implement one-to-one correspondence. Second, gesture may help children to manage the working memory load involved in counting. Because gestures physically mark the child's place in the set of counted objects, so that it need not be stored in working memory, active gestures free up resources that can be used for reciting the string of number words and for coordinating the number words with the objects. Gestures could contribute to counting performance via either or both of these mechanisms.

We believe that understanding children's performance is important, because performance itself can contribute to further development (Sophian, 1997). Successful and unsuccessful performance can provide children with important information about the outcomes and effectiveness of particular procedures (see, e.g., Siegler, 1997; Siegler & Shipley, 1995), and children can use this information both to shape future performance, and to build their conceptual understanding in a domain. For example, children might notice that repeatedly counting the same set in different configurations leads to the same final number tag, and they might use this observation to construct an understanding of conservation of number (see Klahr, 1984). We have shown that counting gestures contribute to accurate counting performance in children. We suggest that, in so doing, counting gestures play a role in the development of number understanding.

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