A Featural Analysis of Preschoolers' Counting Knowledge

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Preschoolers clearly are adept in executing the standard correct counting procedure. Whether they know the principles underlying the procedure is less clear, however. In the present experiments, preschoolers' knowledge of counting principles was investigated by examining their ability to discriminate between features that are essential for correct counting and features that are typically present but unessential. The standard counting procedure was analyzed into one essential feature, word/object correspondence, and four optional features: counting adjacent objects consecutively, pointing once to each object, starting at an end of a row, and proceeding in a left to right direction. The experimenter asked 3- to 5-year-olds to judge acceptable or unacceptable a puppet's counting that either violated the essential feature, that violated one or more unessential features, or that conformed to the standard correct procedure. Children who knew the word/object correspondence principle presumably would reject counts that violated it more often than counts that conformed to it. Each child's skill in counting rows of objects also was assessed. Skill in executing the standard counting procedure was found to precede knowledge of the underlying principle. Four- and 5-year-olds knew that word/object correspondence was essential, although a high percentage of them did not know that other typical features were unessential. An analysis of probable environmental input and of the features' utility in separating already-counted from to-be-counted objects was proposed to account for the relative probabilities that children knew that each of the five features of standard counting was essential or optional.

Psychologists often have characterized preschoolers' knowledge in terms of its deficiencies. Young children have been said to lack understanding of conservation, seriation, class inclusion, perspective, and many other concepts. Recently, however, a number of researchers have noted the limitations of this approach and have suggested that it is more revealing to focus on the capabilities that preschoolers do have (e.g., Brown & DeLoache, 1978; Gelman, 1978; Siegler, 1978). One area in which this suggestion has led to extensive research is counting.

Counting possesses several attributes that make it an attractive subject for study. It is widely thought to be a prerequisite for other mathematical skills, such as addition and subtraction. It is an activity in which young children frequently engage and at which they demonstrate considerable skill (Fuson & Mierkiewicz, 1980; Gelman & Gallistel, 1978; Ginsburg, 1977; Siegler & Robinson, 1982). Finally, the very skill that young children demonstrate while counting makes interesting the question of whether additional development occurs beyond the initially manifested understanding.

Although young children clearly possess considerable knowledge of counting, it is not obvious how best to characterize their knowledge. Gelman and Gallistel (1978) posed one hypothesis: "A knowledge of counting principles forms the basis for the acquisition of counting skill" (p. 204). They inferred that preschoolers know these principles largely on the basis of observations of preschoolers counting sets of objects. This use of the standard counting situation had the advantages of
ecological validity and of maximizing the likelihood that children would understand what they were asked to do. However, it may not have been optimal for distinguishing between whether children knew counting principles or whether their knowledge was limited to an ability to execute standard counting procedures. This last question will be the focus of the present article.

Whether preschoolers grasp principles that underlie procedures is a quite general question, extending well beyond the domain of counting. Investigators have explained an increasing number of young children’s capabilities in terms of principles that guide learning. Bullock, Gelman, and Baillargeon (1982) proposed that young children’s causal attributions are based on knowledge of three principles: determinism (events have causes), priority (causes precede effects), and mechanism (mechanisms necessarily link causes and effects). Starkey and Gelman (1982) argued that a set of arithmetic reasoning principles underlies preschoolers’ performance of addition, subtraction, inversion, and compensation tasks. Other investigators have argued against the view that very young children know these principles. Illustratively, Sophian and Huber (in press) contended that 3-year-olds do not know the causal principle of priority. They argued that 3-year-olds’ successful performance is based on associations between familiar actions and their consequences.

These opposing claims highlight the issue of how we can determine whether children understand principles that underlie procedures. The issue has arisen frequently in the study of language. Linguists and psycholinguists have argued that judgments of acceptability, such as judgments of the grammaticality of sentences, are an especially useful measure (Chomsky, 1968; Gleitman & Gleitman, 1970; Keil, 1981). The logic is that judgments about novel sentences must reflect knowledge of principles, whereas production of grammatical sentences could reflect recall of previously heard statements.

The insight that judgments of acceptability can be used to assess knowledge of language principles appeared equally applicable to assessing knowledge of counting principles. In the present study, we used preschoolers’ judgments of acceptability to examine an intuitively central part of counting knowledge: the word/object correspondence rule. This is the rule that given a correctly ordered list of number words, assigning one and only one number word to each object during counting is both necessary and sufficient to determine a set’s cardinality. The word/object correspondence rule subsumes the information included in Gelman and Gallistel’s (1978) one–one and order-irrelevance principles.

Two departures from standard correct counting seemed likely to be illuminating: unusual correct counts and counts containing errors. Children who know principles underlying counting presumably would discriminate between the acceptability of counts that violate the principles and of counts that conform to them but that are unusual in some unessential way. Children whose knowledge is limited to execution of the standard counting procedure, however, would have no obvious basis for making this discrimination (See Saxe, Sicilian, & Schönfeld, 1979, for a similar argument).

Children’s discriminations between counting errors and unusual correct counts seemed especially useful for evaluating specific computational models of counting knowledge, such as Greeno, Riley, and Gelman’s (1982) SC(01) and SC(02) models. SC(01) consistently rejects counts that violate word/object correspondence but also rejects several types of non-standard correct counts, such as starting in the middle. SC(02) rejects all counts that violate word/object correspondence but accepts all unusual correct counts. If preschoolers rejected both counting errors and unusual correct counts, SC(02) would be rendered an implausible model of their knowledge; if they rejected counting errors and accepted unusual correct counts, SC(01) would be rendered implausible; and if they accepted counting errors, neither model would fit their performance.

Considering the possibility that children might know how to count correctly without knowing the underlying principle raised the issue of how such partial knowledge might develop. Examination of the input that children receive in learning to count suggested one possible process. Learning to count can be thought of as an induction task. Much of the input that children receive comes from watching the counting of others. Children must induce which features are essential for correct
counting and which are optional. At least five features regularly accompany the counting that children see. Only one of these features is essential for correct counting: that exactly one number word be assigned to each object. Four optional features also typically are present, however: adjacent objects are counted consecutively, counting starts from an end of a row rather than the middle, counting proceeds in a left to right direction, and each object is pointed to exactly once.

To determine which, if any, of these features preschoolers use to define correct counting, we presented children with a puppet who counted in a variety of ways; the task was to judge on each trial whether the puppet’s counting was acceptable. The children saw nine types of counts (problem types) which could be divided into three categories. The first category involved counting errors; the four problem-types in this class (the four leftmost problem types in Figure 1) violated the word/object correspondence rule by either assigning more than or fewer than one number word to one of the objects in the row being counted. The second category involved unusual correct counts. The four problem types in this category (the next four problem types from the left in Figure 1) assigned exactly one number to each object, and therefore conformed to the word/object rule, but violated one or more of the four typical but unessential features of counting. The third category involved standard correct counts. These problems tested whether children would judge correct the usual counting procedure executed by another person. Children who knew that only the word/object correspondence rule was essential to correct counting would accept standard correct counts and the four types of unusual correct counts significantly more often than the four types of counting errors. Alternatively, children might know that some but not all unessential features were optional. These children would discriminate some unusual correct counts from the counting errors but not others. The nine problem types also tested the validity of the present featural analysis compared to other possible ones. For example, the word/object correspondence feature could be viewed as two distinct features: no more than one word per object and no fewer than one word per object. If children treated these violations as distinct, they presumably would perform differently on the two counting errors that assigned two number words to an object than on the two that did not assign any.

Another goal of the experiment was to examine whether mastery of the standard counting procedure preceded, followed, or developed simultaneously with understanding of the word/object correspondence rule. Gelman and Gallistel’s view that knowledge of counting principles guides acquisition of counting skill implies that children would recognize that word/object correspondence was essential before, or at least no later than, the time when they counted consistently correctly. By separately assessing knowledge of the principle and of the procedure, we could test this view.
We also examined the effects on children's counting judgments of two other factors: set size and error location. Gelman and Gallistel (1978) reported that children were more accurate in counting small than large sets. They also found that children were most likely to err at the beginning and end of the set, although Fuson and Mierkiewicz (1980) reported that errors were most probable in the middle of sets. To examine the influence of these factors on children's judgments of others' counting, we systematically varied the location of the puppet's departure from correct counting and also the size of the set being counted, as described below.

Method

Participants

Ten 3-year-olds (chronological age [CA] = 47 months), 10 4-year-olds (CA = 57 months), and 10 5-year-olds (CA = 68 months) participated in the study. All were students at a predominantly middle-class preschool. Half of the children in each age group were girls and half were boys. The experimenter was a 28-year-old female postdoctoral student.

Materials

Rows of 3, 4, 9, and 10 plastic chips, pasted \( \frac{1}{2} \) in (1.2 cm) apart on a cardboard strip, were presented to the children. Chips within each row alternated in color (red and green) to maximize the children's ability to distinguish already-counted from to-be-counted objects. The chips were \( \frac{3}{8} \) in. (1.9 cm) in diameter.

Problems

Children were presented nine types of problems: four counting errors, four unusual correct counts, and standard correct counts. As shown at the top of Figure 1, the four counting errors violated word/object correspondence by assigning too many or too few number words to one of the objects. Omitted-word errors (an object pointed to without a word being said) and skipped-object errors (an object neither pointed to nor labeled with a word) involved too few words being assigned to one of the objects. Extra-word errors (an object assigned two number words and one point) and doubly-counted-object errors (an object assigned two words and two points) involved too many words being assigned to one object. Fuson and Mierkiewicz (1980) found that three of these four errors—omitted word, skipped object, and doubly counted object—were the most common correspondence errors made by preschoolers in their own counting of rows of objects.

Of the four types of unusual correct counting, three involved objects being counted in unconventional orders. In reverse-direction counts, the experimenter counted objects in the opposite direction from that in which the child earlier had been observed to count; this almost invariably meant that the experimenter counted from right to left. In start-in-the-middle counts, the experimenter assigned the number "1" to an object in the middle of the row, counted in the same direction as the child until reaching the end of the row, resumed counting in the same direction at the other end of the row, and stopped counting at the object just before the one at which counting had started. In nonadjacent-object counts, the experimenter started from the same end of the row as the child, assigned number words to every second object until reaching the other end of the row, and then reversed directions and counted the uncounted objects (the row was composed of alternating red and green objects, so this was equivalent to counting all of the red chips and then all of the green ones). The fourth type of unusual correct count, double-point counts, violated the typical connection between points and objects; the experimenter assigned each object one number word, but pointed twice to one of the objects (while slowly saying a single number word).

As can be seen in Figure 1, a different combination of problem types violated each feature. Children's patterns of rejections would reveal which feature(s) they thought essential. For example, a child who rejected the leftmost four problem types in Figure 1 and accepted all other counts would be classified as thinking essential the word/object correspondence feature. Children who thought essential more than one feature would judge unacceptable counts that violated any of those features.

Children were presented 72 items of which 48 were counting errors, 16 unusual correct counts, and 8 standard correct counts. The 48 counting errors were the combinations of a 4 (type of error: omitted word, skipped object, extra word, or doubly counted object) \( \times 3 \) (location of error: first object, middle object, or last object in row) \( \times 4 \) (set size: 3, 4, 9, or 10 objects) factorial array. The 16 unusual correct counts were the combinations of a 4 (type of count reverse direction, start in middle, nonadjacent object, or double point) \( \times 4 \) (set size) factorial array. The location of the deviation from standard correct counting was not varied on these trials because it was an integral part of the definition of several of them; for example, start-in-the-middle trials could only start in the middle. The eight standard correct counts were the combinations of a 4 (set size) \( \times 2 \) (repetitions) factorial array.

The 72 trials were separated into four blocks. At the beginning of each one, children were asked to count a row of 10 chips. Following this, the judgment trials were presented 12 counting error trials, 4 unusual correct counts, and 2 correct counting trials in each block. Large sets (9 or 10 objects) were used for half of the trials in each block. Trials were ordered randomly in each block, subject to the constraint that successive trials not involve the same type of count. Testing required two to four sessions, with one or two blocks presented per session, depending on the child's attentiveness.

Procedure

Each trial block proceeded as follows. Children were brought individually from their classrooms to a vacant room in the school and asked to count a row of 10 chips. After praising the child, the experimenter introduced the puppet and said,

Now, Scruffy is going to count for you. Scruffy is just learning how to count. Sometimes when he counts, he
makes mistakes. He knows his numbers, but sometimes when he counts the chips, he does it wrong. Scruffy is going to do some counting for you. I want you to watch him very carefully to see if he makes a mistake. Let's try one for practice. Watch carefully

Scruffy then counted the row of 10 chips, skipping three adjacent chips in the middle of the row and one at the end (these errors were used because pilot testing indicated that almost all children recognized them as mistakes). The 18 trials in the block then were presented. On each trial, after the puppet counted the objects, the child was asked "Did Scruffy make a mistake?"

Results

An initial issue concerned the judgment task’s validity; would preschoolers understand what they were asked to do, and would their judgments of the puppet’s counting be related to their own counting. The experimental results suggested affirmative answers to both questions. As will be described in detail below, at all three ages children discriminated among the nine types of counts in an intuitively sensible fashion; this suggested that they understood the task. In addition, children’s judgments of counting accuracy were related to their proficiency at executing the typical counting procedure. Thus, the children’s judgments of counting errors seemed a reasonable index of their counting knowledge.

Analyses of children’s judgments were conducted at two levels of aggregation. First, we performed group-level analyses to reveal whether children discriminated among the acceptability of different counts. Second, we examined individual children’s performance to determine which features they thought to be essential and to determine the relation between their counting judgments and their counting skill.

Group-Level Analyses

Discriminations among problem types

Children who understood the word/object correspondence rule would be expected to discriminate between the four counting errors that violated the rule and the five unusual correct and standard correct counts that conformed to it. To examine children’s discriminations among the problem-types, we performed a 3 (age) × 9 (problem-type) × 2 (set size) analysis of variance (ANOVA) on the proportion of trials on which children rejected each type of count. This analysis indicated significant main effects for age, F(2, 27) = 6.42, p < .01, and problem type, F(8, 216) = 53.96, p < .001. Significant effects also emerged for the Age × Problem Type interaction, F(16, 216) = 2.02, p < .05, and for the Set Size × Problem Type interaction, F(8, 216) = 8.08, p < .001. A Newman-Keuls test revealed that the main effect for problem type was due to all of the counts with errors more often being rejected than the standard correct counts and two of the four unusual correct counts (reverse direction and double point; p < .05). The main effect for age was due to the 3-year-olds rejecting fewer counts across all of the problem-types than the 4- and 5-year-olds.

To interpret the Age × Problem Type interaction, separate Newman-Keuls analyses were performed for each age group on the children’s discriminations among the nine problem types. Two facts stood out in these analyses. First, as shown in Table 1, the rank orders of proportion of rejections of the nine problem types were almost identical for the 3-, 4-, and 5-year-olds. The proportions of rejections correlated as follows: r = .95 for the 3- and 4-year-olds, r = .95 for the 4- and 5-year-olds, and r = .97 for the 3- and 5-year-olds (Spearman rank-order correlations, ps < .01). For all three age groups, skipped-object counts were the most likely to be rejected; for all three, standard correct and reverse-direction counts were the least likely to be. Second, the degree of differentiation among the problem types increased substantially in this age range. At one extreme, 5-year-olds significantly discriminated all four of the counts that violated the word/object correspondence rule from all five of the counts that conformed to it. At the other extreme, 3-year-olds significantly discriminated all four counts with errors from only the standard-correct counts, though they also significantly discriminated some of the unusual correct counts from some of the counts that involved errors (all ps < .05).

The significant set size by problem-type interaction reflected a pattern analogous to the one in the age by problem type interaction, with performance on small-set trials resembling that of the older children and performance on large-set trials resembling that of the younger ones. The orderings of the pro-
Table 1  
**Newman-Keuls Analyses of Proportions of Rejections of Each Problem Type**

<table>
<thead>
<tr>
<th>Problem Type</th>
<th>Group</th>
<th>Skipped object</th>
<th>Doubly counted object</th>
<th>Omitted word</th>
<th>Extra word</th>
<th>Nonadjacent object</th>
<th>Start in the middle</th>
<th>Double point</th>
<th>Reverse direction</th>
<th>Standard correct</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3-year-olds</td>
<td>0.72</td>
<td>0.49</td>
<td>0.50</td>
<td>0.92</td>
<td>0.35</td>
<td>0.35</td>
<td>0.18</td>
<td>0.12</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>4-year-olds</td>
<td>0.92</td>
<td>0.74</td>
<td>0.82</td>
<td>0.68</td>
<td>0.62</td>
<td>0.28</td>
<td>0.05</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5-year-olds</td>
<td>0.97</td>
<td>0.54</td>
<td>0.93</td>
<td>0.91</td>
<td>0.52</td>
<td>0.42</td>
<td>0.15</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: Underscoring indicates probabilities that are not significantly different, $p < .05$.

Portions of rejections of the problem types were similar for the two set sizes; the Spearman rank-order correlation was .97 for the small and large sets. However, separate Newman-Keuls analyses for each set size indicated that children discriminated among the nine problem types to a greater extent on small- than on large-set trials. On small-set trials, children were significantly less likely to reject standard correct counts and reverse-direction counts than the other unusual correct counts and were less likely to reject all correct counts than any count involving errors. On large-set trials, children's only discrimination was between standard correct, reverse-direction, and double-point counts on the one hand, and all of the counts with errors and the two remaining unusual correct counts on the other (all $ps < .05$). 

**Error location.** To evaluate the effect of error location, a $3 \times 4 \times 2 \times 3$ ANOVA was conducted on the proportion of trials on which children rejected counting errors (the only problem types on which location of the deviation from standard correct counting was varied systematically). The analysis yielded a significant main effect for error location $F(2, 54) = 3.73$, $p < .05$, as well as other main effects and interactions similar to those found in the larger ANOVA described above. Across the four problem types, children rejected a significantly higher percentage of errors that occurred at the end of the row than in the middle or beginning.

1 The nine problem types differed substantially in variability. To examine the effects of this heterogeneity, we performed arc sine transformations on the data and then repeated the statistical tests described above on the transformed data. All significant main effects and interactions in the ANOVA again were found. The results of a Newman-Keuls analysis also yielded the same pattern as in Table 1.
Table 2
Number of Children Thinking Each Feature Essential (Among 10 in Each Age Group)

<table>
<thead>
<tr>
<th>Group</th>
<th>Word/object</th>
<th>Adjacency</th>
<th>Start at an end</th>
<th>Pointing</th>
<th>Standard direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-year-olds</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4-year-olds</td>
<td>9</td>
<td>6</td>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>5-year-olds</td>
<td>10</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

(69% vs. 57%), *t*(29) = 2.21, *p* < .05. This pattern suggests a recency effect; children were most likely to report errors that occurred closest in time to when they responded. Error location did not interact with any of the other factors.

**Analysis of Individual Performance**

**Counting judgments.** Table 2 indicates the numbers of 3-, 4-, and 5-year-olds who thought each of the five features to be essential. For word/object correspondence, adjacency, pointing, and standard direction, the criterion for classifying a child as thinking a feature essential was that the child reject at least 75% of the items of each problem type that violated the feature. For example, as shown in Figure 1, a child classified as thinking essential pointing would need to reject at least 75% of doubly-counted-object, 75% of skipped-object, and 75% of double-point counts. Because only the four start-in-the-middle counts could be used to assess knowledge of the start-at-an-end feature, children were required to reject all four of those counts to be classified as thinking the feature essential. Rejections rather than acceptances of the puppet’s counting were used as the primary data because viewing a feature as essential justifies rejections of counts that violate it. No view about whether a single feature was essential could justify an acceptance of a given count.

As shown in Table 2, more older than younger children distinguished essential from optional features of counting. Significantly more 5-year-olds viewed word/object correspondence as essential than viewed any of the other features as being so (binomial test, all *p* < .05). Significantly more 4-year-olds viewed word/object correspondence as essential than viewed either standard direction or pointing to each object as such. Finally, although a greater number of 3-year-olds viewed word/object correspondence as essential than so viewed any other feature, the differences were not significant.3

As part of the featural analysis, we examined whether children viewed word/object correspondence as one feature (say one word per object) or as two features (say no more than one word per object and say no fewer than one word per object). To perform this test, we divided the four problem types that violated word/object correspondence into the two that included too many number words and the two that did not include enough. Of the 30 children, 28 either consistently rejected both types of violations or rejected neither of them. Thus the children appeared to think of word/object correspondence as a single feature.

Table 3 illustrates the combination of features that each child thought essential. If we assume that children were most likely to think word/object correspondence essential, and next most likely to think adjacency, starting

2 The probability that a random responder would be misclassified as thinking a feature essential varied somewhat but not greatly among the five features. The binomial probabilities of such a misclassification were *p* = .06 for the start-at-an-end feature, *p* = .02 for the standard direction feature, and *p* < .01 for the adjacency, pointing, and word/object correspondence features.

3 To determine whether these results depended on the particular classification standards that were used, we performed two other featural classifications, one with more stringent and one with more lenient criteria. The more stringent criteria required rejection of the counts on 100% of trials for the start-at-an-end feature and 85% of trials for each problem type that violated the other four features. The more lenient criteria required rejection of 75% of the start-at-an-end feature and 65% for the items of each problem type that violated the other four features. When the criterion was lowered from 75% to 65%, only 3% of the featural classifications changed; when it was raised from 75% to 85%, only 7% of the classifications changed.
at an end, pointing, and standard direction essential, in that order, only 3 of 30 children departed from a Guttman scale pattern. In addition, two of the three departures seemed due to the low power of our assessment of the start-at-an-end feature. Had we been able to adopt the same 75% rejections criterion for this feature as for the other four, these two children would have been classified as fitting into one of the expected patterns.

The eight children who did not indicate knowledge that word/object correspondence is essential (see Table 3) were of special interest; did they know that any violation of word/object correspondence was unacceptable? Examination of the four counting errors indicated that three of the eight children consistently (on at least 75% of relevant trials) judged skipped-object counts unacceptable. Two additional children consistently indicated on small set trials that skipped object counts were wrong. No other type of count was consistently rejected by more than one of the eight children on small- or large-number trials. Thus children may recognize that doing something with each object is essential before they recognize that assigning exactly one number word to each object is.

Relation between counting judgments and counting performance. Children's rejections of counting errors were closely related to their counting performance. Of the 30 children, 22 counted correctly on at least 75% of trials and also rejected at least 75% of counting errors. An additional four children met neither criterion. The remaining 4 children counted correctly on at least 75% of trials but did not consistently reject the puppet's counting errors. Seen from another perspective, the 26 children who counted correctly on at least three of the four trials rejected 86% of the puppet's counting errors; the 4 children who erred on two or more of their four counts rejected only 32%.

Discussion

The results of this experiment indicated that, with age, increasing numbers of children realize that correct counting requires assignment of one and only one number word to each object. Only 3 of ten 3-year-olds consistently rejected counts that violated word/object correspondence, whereas 19 of twenty 4- and 5-year-olds did so. The results also indicated that children realize the essential or unessential nature of some features of standard correct counting before others, rather than understanding all of them at once. In particular, a high percentage of 4- and 5-year-olds knew that assigning one number word to each object is essential and that counting in the standard direction is unessential, but also thought that counting adjacent objects consecutively and starting at an end were essential. The 4- and 5-year-olds' rejection of counting errors and also of many unusual correct counts was consistent with Greeno, Riley, and Gelman's SC(ol) model of how children evaluate other people's counting but not with their SC(o2) model. The 3-year-olds' frequent acceptance of the puppet's counting errors was not consistent with either model.

The results left unresolved two issues. First, do children correctly execute the standard counting procedure before they know the word/object correspondence principle, do they know the principle before they know the procedure, or are the two competencies acquired simultaneously? Second, did misunderstanding of the task lead to the 3-year-olds' frequent acceptance of the puppet's counting errors? Experiment 2 was designed to address these issues.

Experiment 2

The initial experiment did not yield conclusive evidence concerning whether children
learned the standard correct counting procedures before, after, or simultaneously with the word/object correspondence principle. The large majority of children, including 19 of the twenty 4- and 5-year-olds, consistently counted correctly and consistently rejected counts that violated word/object correspondence. All 4 children who succeeded on one task but not the other showed a single pattern: They counted correctly and did not reject counts that violated word/object correspondence. However, 4 children was too small a group to allow firm conclusions. Therefore, one purpose of Experiment 2 was to compare the counting and judgment performance of a larger number of 3-year-olds who had not yet acquired both types of knowledge.

The second issue addressed by the experiment was the degree to which children understood the task. The original data indicated that the youngest children understood that they sometimes should reject the puppet's counting, but also provided some support for the view that they may have been unsure how large the puppet's error needed to be before it was unacceptable. First consider the evidence that children understood the task requirements. All 30 children judged the puppet's counting to be correct on at least 11 trials, and all of them judged the puppet's counting to be incorrect on at least 11 trials. Thus, none of them blindly accepted or rejected all counts. Even more striking, children of all three ages rejected some types of counting far more often than others. Three-year-olds rejected skipped object counts on 72% of trials and standard correct counts on 5%; the comparable figures for 4-year-olds were 92% and 2% and for 5-year-olds 97% and 0%. Thus even the youngest children saw the counts as different from each other and differentially acceptable. Finally, counting judgments were related to counting performance: the children who least often counted correctly least often rejected the puppet's counting errors. Each of these findings supported the view that differences in knowledge of counting produced the youngest children's acceptances of counting errors.

Other aspects of the data, however, suggested that 3-year-olds may not have been as confident as older children that it was acceptable to reject the puppet's counting as incorrect. Across all problem types, they rejected a lower percentage of the puppet's counts than did the older children. This lower likelihood of rejecting the puppet's counts may have been the reason that they actually were correct more often than the 4- or 5-year-olds in accepting the unusual correct counts. The youngest children may have believed that only blatant errors should be judged incorrect and therefore may have lumped together correct counts and errors that they thought the experimenter would not mind.

In Experiment 2, we modified the original judgment procedure to clarify the criterion for acceptable counting. Before judging the puppet's counts, children saw an adult model perform the task. The adult said "No, Scruffy's counting was not OK" on the four counting-error trials, and said "Yes, Scruffy's counting was OK" on the five standard correct and unusual correct counts. The experimenter praised the model after each response. This demonstration illustrated the desired cutoff point between correct and incorrect counting. In addition, at the end of the instructions, the experimenter provided children an additional reminder "Remember, sometimes Scruffy's counting is OK, and sometimes his counting is not OK. So, sometimes you should say 'Yes it is OK' and sometimes you should say 'No it isn't OK.' " This procedure was intended to increase the 3-year-olds' willingness to reject the puppet's counting.

Eight boys and eight girls from the same preschool as children in the original experiment participated. Their mean age was within 1 month of that of the 3-year-olds in the earlier study (CA = 47.8). The procedure and materials used to assess the children's own counting were identical to those in the original experiment except for three changes. First, each problem type was presented on two trials of each set size (3, 4, 9, 10) for a total of eight trials per problem type. Second, error location was omitted as a variable; all errors occurred in the middle of the row. Third, at the beginning of each of the four trial blocks, children counted both a small and a large set row. The procedure and materials were identical to those used previously except for the addition of the modeling procedure and the new instructions noted in the previous paragraph. The experimenter was a 25-year-old female research assistant.

We found that 9 of the 16 children counted correctly on at least 75% of their own counts
and rejected fewer than 75% of the puppet's counting errors. In contrast, 0 of the 16 children rejected 75% or more of the puppet's counting errors and counted correctly on fewer than 75% of their own counts (binomial probability, \( p < .01 \)). When only judgments and counts of small sets were considered, 11 of the 16 children counted accurately but did not consistently reject the puppet's incorrect counts; again, no child who consistently rejected the puppet's counting errors failed to count consistently correctly \( (p < .001) \). (The remaining 5 children consistently counted correctly and also rejected the puppet's errors.) Thus children appeared to know the counting procedure before the underlying principle.

The second issue was whether seeing an adult model reject the counting errors would lead 3-year-olds to do the same. The modeling procedure did not produce this effect. Children rejected 39% of all counts, as opposed to 37% for age peers in the earlier experiment. They actually rejected a nonsignificantly smaller percentage of the puppet's counting errors than in the previous study: 51% versus 58%. A one-way ANOVA on children's proportions of rejections of each of the nine problem types yielded a significant main effect for problem type, \( F(8, 120) = 8.81, p < .001 \). A Newman-Keuls analysis revealed that the effect was due to standard correct and reverse-direction counts being rejected less often than any of the other counts, and skipped-object counts being rejected more often \( (ps < .05) \). The proportions of trials on which the other three unusual correct counts and the other three counting errors were accepted did not differ significantly. Only 2 of 16 children met the criterion for knowing that word/object correspondence was essential. Even considering small-set trials alone, only 5 of 16 met the criterion. Thus, the results provided no obvious support for the misunderstanding of task interpretation. Seeing the adult model's judgments had little effect on the children's performance.

### General Discussion

The experimental results demonstrated the usefulness of viewing children's counting knowledge in terms of their knowledge of essential and optional features. At no point in the age range that we sampled did children's knowledge appear to be limited to the standard counting procedure. Also, however, at no point did the majority of children rely solely on the word/object correspondence rule. Instead, it appeared that children very early learn to execute the standard counting procedure and then gradually learn which of the typical accompaniments of counting are essential and which are optional. The process of discriminating acceptable from unacceptable counts appeared to have begun by age 3, to progress considerably between ages 3 and 5, yet still to be incomplete at age 5.

First consider the evidence that by age 3, children have begun to distinguish acceptable from unacceptable counts. Perhaps the strongest evidence was that 3-year-olds' proportions of rejections of all four counting errors were higher than their proportions of rejections of any of the four unusual correct counts. Summing across the four counting errors and including children from both experiments, 3-year-olds rejected significantly more counting errors (55%) than unusual correct counts (31%), \( t(25) = 3.47, p < .01 \). Their rank orders of proportions of rejections of the nine types of counting also correlated highly with those of the 4- and 5-year-olds.

Next consider the evidence that children's ability to distinguish between essential and optional features of counting grows considerably in the preschool period. Five-year-olds, unlike 3-year-olds, were significantly more likely to accept each of the unusual correct counts than any of the counts containing errors. Similarly, 5-year-olds, unlike 3-year-olds, were significantly more likely to consider word/object correspondence essential than any of the other features.

Now consider the evidence that knowledge of the word/object correspondence rule remained incomplete even among the oldest children who we sampled. The featural analysis indicated that all 10 of the 5-year-olds viewed word/object correspondence as an essential feature of counting, but it also indicated that only 4 of the 10 viewed it as the only essential feature. A majority of the 5-year-olds thought that adjacency, starting at an end, and/or pointing also were essential for correct counting.

Children were found to count correctly before they consistently judged incorrect another individual's counting errors. To the extent that
such judgments are a valid index of principled knowledge, as numerous linguists and psycholinguists have argued, it follows that children can execute the correct procedure before they know the underlying principle. This finding holds with either a strict or a relaxed definition of principled knowledge. The strict criterion corresponds to the use of Greeno et al.'s SC(o2) mechanism in which children view word/object correspondence as the sole defining quality of correct counting. By this criterion, counting errors consistently are rejected and standard correct and unusual correct counts are consistently accepted. In Experiment 1, 26 of 30 children counted consistently correctly, whereas 9 of 30 viewed only word/object correspondence as essential for correct counting. The looser criterion, corresponding to Greeno et al.'s SC(o1) mechanism, demands only consistent rejection of counting errors. Four of the 30 children in Experiment 1, and 9 of the 16 in Experiment 2, counted consistently correctly but did not consistently reject the puppet's counting errors. No children in either experiment consistently rejected the puppet's counting errors. This ordering renders improbable the view that knowledge of principles guides acquisition of procedures in the domain of counting. Whether knowledge of principles guide acquisition of procedures in other domains, such as causality and arithmetic, remains a subject for further empirical investigation.

Among the four typical but unessential features, standard direction was known to be unessential by the greatest number of children, followed by pointing, starting at an end, and adjacency. A remaining question concerns why more children realized that some of these features were unessential than realized that others were. Considering the range of counts on which the features are adhered to, and the usefulness of the features for separating already-counted from to-be-counted objects, suggests one possible explanation.

Proceeding in the standard direction probably is the feature least often adhered to in the counts children see. Vertical columns cannot be counted from left to right. On horizontal rows, counting direction varies with the position of the observer; a child sitting next to an adult counting from left to right sees it as a count in that direction, but a child facing the adult sees a right to left count. Proceeding from left to right is not useful for separating counted from to-be-counted objects (Beckwith & Restle, 1966). Thus, children might quickly come to see counting in the standard direction to be unessential.

People have more reason to point to each object. It seems useful for helping to discriminate between already-counted and to-be-counted objects. It also can be used with all types of static arrangements and does not depend on the observer's position. However, it is not useful in any obvious way in counting sequential events. For example, there seems to be little advantage to pointing while counting the chimings of a churchbell.

Adjacency and starting-at-an-end seem the most difficult features to recognize as optional. There are several reasons why most counts that children see would include these features. They help separate counted from to-be-counted objects, can be applied to all types of static arrangements, and also are adhered to in counting sequential events. Children may start counting stairs from either end, and may not point to each stair, but rarely if ever start in the middle of the stairs, reach the top or bottom, and continue from the other end. Nor are they likely to count every other stair and then return to the remaining ones. Not only are such violations of adjacency and starting at an end difficult to imagine in the stair-counting situation, they are almost inconceivable in counting the chiming of churchbells. Thus, starting at an end and counting adjacent objects consecutively probably accompany most counts that children see and do. This regularity makes less surprising the finding that many 5-year-olds think adherence to these features essential.

What type of input would help children discover that these features are optional? One discovery process is illustrated in a well-known anecdote:

He (a boy of 4 or 5 years) was seated on the ground in his garden and he was counting pebbles. Now to count these pebbles he put them in a row and he counted them one, two, three, up to ten. Then he finished counting them and started to count them in the other direction. He began by the end and once again he found he had ten. He found, this marvelous . . . so he put them in a circle and counted them that way and found ten once again. (Piaget, 1964; p. 120)

As described, this boy's experiment suggested that standard direction and starting at an end
are optional features of counting. The experiment could be extended to the adjacency and pointing features. The prevalence of children performing such experiments is unknown, but their possibility does provide a route by which children could induce that starting at an end and counting adjacent objects consecutively are optional, thus leaving word/object correspondence the only feature thought essential.

References


Received February 15, 1983
Revision received March 28, 1983