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THE FUNCTION OF GESTURE IN THE COUNTING ACTIVITIES OF VERY
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City University of New York

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THE FUNCTION OF GESTURE IN THE COUNTING ACTIVITIES
OF VERY YOUNG CHILDREN

by

ROCHELLE GOLDBERG KAPLAN

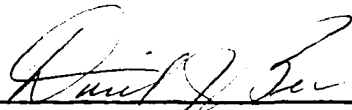
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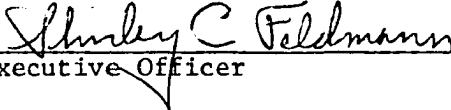
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This manuscript has been read and accepted for the Graduate Faculty in Educational Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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Abstract

THE FUNCTION OF GESTURE IN THE COUNTING ACTIVITIES
OF VERY YOUNG CHILDREN

by

Rochelle Goldberg Kaplan

Advisers: Professors Geoffrey Saxe and David Bearison

Overt pointing gestures have frequently been observed to accompany the counting activities of very young children. It has generally been assumed that these gestures serve as an aid to counting accuracy, as they do in older children. Much research, however, indicates that younger children do not appreciate the numerical concepts underlying the counting process and, therefore, are not attempting to achieve an accurate count. It is unlikely, then, that gesture has a partitioning or tracking function in early counting activities. Instead it was hypothesized that gesture, having its roots in the symbolic activities of the late sensori-motor period of development, serves a referential rather than partitioning function in the counting activities of very young children. Only later as quantitative understanding develops should gesture shift in function to help in obtaining an accurate count.

The purpose of this study was to examine the development of the function of gesture in the counting activities of children between 2 and 8 years of age. Three groups of 20 children, ages 2 to 3, 4 to 5, and 7 to 8, were presented with labeling and counting tasks in which they were and were not permitted to use gestures. It was expected that the shifting function of gesture over development would be reflected in the children's varying performances on these tasks.

The results indicated that 2- to 3-year-olds tended to use gestures in synchrony with their verbalizations. They counted more accurately with than without gestures, but were consistently less accurate than 4- to 5- and 7- to 8-year-olds. They also labeled more accurately than they counted and tended to deploy gestures unsystematically. Four- to 5-year-olds counted more accurately when gestures were allowed and, with gestures, could count as accurately as 7- to 8-year-olds. They counted as accurately as they labeled and deployed gestures in an orderly manner. Seven-year-olds were consistently accurate on both counting and labeling tasks with or without the use of gestures. They tended to use gestures infrequently, but when used, deployed them in an orderly direction.

It was concluded that for 2- to 3-year-olds, gesture was used referentially and made counting more like a labeling task by supporting the process of assigning individual words to particular objects. For 4- to 5-year-olds, the function of gesture shifted to serve as a partitioning aid for separating objects counted from those yet to be counted and was necessary for obtaining counting, but not

labeling accuracy. For 7- to 8-year olds, gesturing was not necessary for obtaining accuracy, but when it did occur, probably continued to serve a limited partitioning function.

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CHAPTER I

Introduction

Overview

The prevalent use of spontaneous gestures in the counting activities of very young preschool children has been amply documented by many researchers in early number concept development (Gelman & Gallistel, 1978; Ginsburg & Russell, 1981; Klahr & Wallace, 1973, 1976; Potter & Levy, 1968; Schaeffer, Eggleston, & Scott, 1974; Silverman & Rose, 1980). The function of gesture, however, has usually been assumed to serve the same purpose regardless of the child's level of counting proficiency, i.e., to aid in obtaining an accurate count. Underlying this assumption is the notion that the young child's counting efforts are an equivalent, if imperfectly executed, form of mature counting behavior. From this point of view, even the very young child, as early as age 2, is believed to be capable of understanding basic counting principles and numerical relationships.

An alternative point of view is that the child's understanding of numerical relationships varies over development and that early counting activity does not imply an appreciation of the necessity of establishing a one-one correspondence between each number name and object (Piaget, 1965). Without an appreciation of this necessity, however, it cannot be assumed that the child is utilizing gesture to aid in obtaining an accurate count since there is a lack of understanding of what an accurate count entails. Rather, at this level the gesture, having its roots in earlier non-numerical forms of symbolic activity, may serve the function

of referencing or assigning names to objects rather than the function of partitioning objects in order to account for each and every item once and only once. The purpose of this study is to investigate the possibility that the child's use of gesture in early counting activities is structurally isomorphic to the use of gesture in other non-numerical language activities and that only as the child's understanding of the quantitative relationships within a counting context develops, does the use of gesture take on the specific function of helping to insure an accurate count.

Review of the Literature

The Maturationist Tradition

The assumption that the form of a child's knowledge is no different from that of an adult's has been the basis of much early childhood research beyond the realm of counting in number concept development. Within the framework of this maturationist tradition studies have attempted to demonstrate that very young children are capable of performing the logical processes associated with Piaget's concrete operational period of development (see Flavell, 1963, or Piaget & Inhelder, 1969, for a discussion of concrete operational capabilities). By means of adapting Piaget's original tasks, investigators have reported results indicating that very young children at preschool ages are capable of making transitive inferences (Bryant, 1977; Bryant & Trabasso, 1971), understanding class inclusion relations (Markman, 1978, 1979; Smith & Rizzo, 1982; Wilkinson, 1976), solving seriation problems (Koslowski, 1980), and conserving continuous quantities (Bruner, 1966).

Typical of the kind of task adaptation utilized in these studies is Wilkinson's (1976) simplification of the class inclusion problem.

He provided 4- and 5-year-old preschool children with sets of three pictures, two of which represented one subordinate class and one of which represented another. The three pictures together constituted the entire superordinate class. In addition to reducing the number of items in each class, as compared to Piaget's (1965) original task which included some 10 to 20 items in the superordinate class, Wilkinson also directed some of the children to point to each item in each class before answering the inclusion questions. The children were then prompted to correct themselves if items were omitted. He also included problems with perceptually based classes as well as those involving conceptually based classes (i.e., houses with windows vs. all houses as contrasted to boys vs. children). Because preschool children were observed to be capable of correctly solving some class inclusion problems within these contexts, Wilkinson concluded that class inclusion errors in young children are the outcome of faulty problem solving strategies and not a reflection of logical deficits.

Using an analogous paradigm for task simplification on a test of children's understanding of seriation problems, Koslowski (1980) found that nursery school children who were classified as non-operational on Piaget's original seriation task involving 10 sticks could systematically seriate a smaller series of four sticks when given specific task orienting instructions. She claimed that systematic performance on the easier task indicated the presence of the same operational abilities as those found in children who could seriate 10 sticks. Koslowski interpreted these results as providing evidence that conflicts with Piaget's findings although Piaget did not claim that younger children were incapable of

performing this task with fewer sticks. The conflict, therefore, seems to be more one of interpretation of data than one of discrepancy between observed performance.

In the literature on number concept development coming from a strong maturationist tradition, one of the earlier and more controversial studies done indicating that preschool children possess an understanding of quantitative relationships equal in logic to that of so-called operational children was done on number conservation by Mehler and Bever (1967). They presented children from the ages of 2 to 4 1/2 with two static rows of objects differing in numerosity and spatial extent and found that the youngest children consistently were able to distinguish the more numerous row regardless of differences in spatial extent. They found also that this response decreased with age, from which they concluded that young children are natively endowed with the ability to conserve, but that as they get older, perceptual expectancies interfere with logical strategies until at a later age children are able to integrate the two processes. Unfortunately, their measure is not really one of conservation as Piaget described his procedure since no spatial transformations were performed on sets whose initial equivalence had been established. The so-called native endowment of the logic of conservation, therefore, was not tested in this study. In response to such criticism, the study was adapted to include a condition in which spatial transformation was performed on initially equivalent sets (Bever, Mehler, & Epstein, 1968). Again they found the same age-related patterns of successes and failures, but again they confounded the task by including subjects as correct in assessing the transformed arrays even if they did not make a correct initial judgment of equality (Beilin, 1968).

Other conservation studies claiming to test the concept of conservation of quantity over spatial transformations have also attempted to demonstrate that children of preschool age are capable of the logical operations needed for the task. Miller's (1980) adaptation of the number conservation task with 4- and 5-year-olds focused on the meaningfulness of task context. In his study comparing a standard administration and a "motivated choice procedure" he found that children could conserve more readily when they had to decide if they really had been given more candies to keep instead of being asked if they still had the same number of candies after a transformation. In the motivated choice procedure, however, candies were sometimes added and subtracted by a puppet and the children were told that some trickery might be involved. On this task again, then, understanding that numerical equality is maintained over spatial transformations was confounded with distinguishing between a trick condition (i.e., the numerically irrelevant transformation) and addition or subtraction operations. Miller, nevertheless, accepted the superior performance of children on the motivated choice procedure as evidence that 5-year-olds were capable of conserving number.

Gelman extended her earlier conservation research (1969), demonstrating that 5- and 6-year-olds could conserve number when trained to attend to relevant rather than extraneous attributes of the problem, to include the numerical reasoning capacities of 2-, 3-, and 4-year-olds (Gelman, 1972; Gelman & Gallistel, 1978). She studied the capacity of 2- to 5-year-olds to regard numerosity as a salient feature of arrays and to make use of counting as a numerically meaningful tool. Much of these data were obtained from a paradigm called "the magic experiment" in

which children had to select the "winner" of two arrays based on which of the arrays was more numerous before and after transformations. The arrays consisted of miniature toy mice which were either spatially transformed after concealment or from which one mouse was surreptitiously added or removed. In general, children in these studies tended to focus on number and not irrelevant attributes in making their judgments.

In their 1978 investigation of children's counting activities, Gelman and Gallistel proposed some counting principles that guided the young child's enumeration efforts. The principles included the one-one principle, the stable-order principle, the cardinal principle, the abstraction principle, and the order-irrelevance principle. They videotaped and observed about 75 2-, 3-, 4-, and 5-year-olds counting and making numerical comparisons between colored chips of set sizes 2, 3, 4, 5, 7, 11, and 19. Although this study was viewed as providing supporting evidence for the notion that young children understand more about numerosity than was previously acknowledged, their interpretation of successful performance was based on rather liberal scoring standards. For example, they accepted idiosyncratic number word lists as evidence of the stable-order principle and as evidence of accurate counting. They also defined counting accuracy, even on small set sizes, as equivalence between set size and the number of words uttered, plus or minus one. In addition, the data were reported largely in terms of means and percentages without being subjected to standard procedures of statistical analysis. Finally, their interpretation was based primarily on results found with small set sizes and may have been biased because 2-year-olds and even some 3-year-olds had to be dropped from parts of

the study due to the children's failure to complete all tasks or make judgments based on numerosity consistent with the researchers' scoring system. Nevertheless, based on the magic and videotape studies, Gelman concluded that very young children had some numerical counting capabilities that did not differ qualitatively from those of adults and which required only practice, experience, and increased motor coordination in order to be fully realized.

In later studies Gelman and her colleagues extended this notion of young children's numerical competence to include 6- to 8-month-old infants (Starkey, Spelke, & Gelman, 1983) and made the point that these abilities are innate (Gelman, 1982). In the infant study she and her colleagues used pairs of visual displays and numerically corresponding singlets of drumbeats of set sizes 2 and 3. The infants were expected to stare longer at displays that matched an equal number of drumbeats. They found that a majority of infants preferred the corresponding display on the second half of the trials although on the first half of the trials, the majority preferred set size 3 regardless of the auditory stimulus. Again no statistical analysis was used to determine whether these findings were merely due to chance. Although there is no reason to assume that the infants were in any way intending to match sets even when they actually did so, Gelman and her associates regard the results of this study as providing evidence that infants can detect numerical correspondences across different sense modalities.

In the study in which Gelman inferred that children's assessment of one-one correspondences is innate (Gelman, 1982), 3- and 4-year-old children were trained to use counting and cardinality in order to perform

a conservation task. Although the results indicated that three-quarters of the 4-year-olds and half of the 3-year-olds did conserve after training, some of the younger subjects were dropped from the study because they could not follow directions. In addition, only percentages without any statistical analysis were utilized as evidence of successful training.

Critique of Studies in the Maturationist Tradition

The interpretation of the evidence of the above types of studies is limited by two theoretical constraints. The first is that all correct responses are accepted as formally or structurally equivalent and does not allow for the possibility that the same observable behavior may serve different functions or derive from a variety of thought processes (DeBoysse-Bardies & O'Regan, 1973). In Miller's (1980) study, for example, one might suggest that children were prepared to be tricked and so set up a trick of their own. That is, whenever they believed that an array had been changed by a spatial transformation, they would purposely guess the opposite, i.e., that no change was made, in order to trick the experimenter. While this too implies some sophisticated reasoning, it does mean that children were not necessarily conserving number. Similarly the young children whom Gelman and Gallistel (1978) cite as being guided by how-to-count principles, may have been guided more by an effort to imitate the external forms of counting such as reciting a chain of number names while pointing. There is a similarity here to the child who learns to play the piano and in doing so takes on all the mannerisms of his/her teacher. Although the mannerisms appear to be part of the technique, in reality they may have no effect on the

music. The child, however, does not distinguish between the relevant and irrelevant aspects of the teacher's playing because he/she does not yet understand the theory or principles behind the music. In Gelman and Gallistel's studies, success with external forms of counting may have reflected a fortuitous match between the young child's minimal expertise with the form in conjunction with the opportunity to apply it to small set sizes, rather than an underlying capacity for numerical representation. That is, the child may have known only a short list of number names and so this list fit, by chance, the actual set size.

The second theoretical constraint, following from the first, is that although task complexity and criteria for success are often reduced for younger children, it is still assumed that all subjects are participating in the same cognitive activity (Brainerd, 1973, 1978). Even if one were to assume that all children and adults do have the same underlying intellectual capacities, there is reason to believe that oversimplifying a task to accommodate for the limited experience of very young children destroys the logic of the task in its original form. For example, in Wilkonson's (1976) study of class inclusion cited earlier, sets of only three pictures in which two of the three belonged to the same subordinate class were utilized. By using three rather than 10 or 20 items, the task problem became one in which two items were to be classified as the same and one was classified as different. This distinction highlighted the separateness of the single item and made it less likely to be confused with the superordinate class category during questioning. That is, if there were two boys, one girl, and three children, the subject would have an easier time keeping the boy-girl relationship separate from the

boy-children relationship. Moreover, the children in this study were encouraged to count and so in dealing with set sizes of 1, 2, and 3, the task became one of numerical comparison within the subitizing range. Within this range even the young child could understand that three was more than two or one. What the child did not necessarily grasp was that two and one were subsets of three and that together they constituted the category of threeness. The same would be true of the boy, girl, children categories. That is, even though the subjects selected "children" as the more numerous group, this did not imply an understanding of the logical relationship of boys and girls as the subclasses of the superordinate class called children. Thus, because the task was simplified to produce greater success at an earlier age, the logic of the original problem was lost. The point then is that if tasks are not structurally equivalent, it cannot be assumed that all individuals have utilized the same principles or cognitive capacities to solve the various problems. Therefore, the apparent uniformity of cognitive functioning over development is more of an experimental artifact than a product of equivalent underlying cognitive capacity.

The Constructivist Tradition: Evidence Against the Functional Uniformity of Gesture in Counting

With regard to the utilization of gesture in counting activities, there are two bases in the literature that seriously call into question the validity of an assumption of functional uniformity. The first and more fundamental basis for doubting the assumption of a uniform function of gesture in counting activity at all levels of development is the research demonstrating that the child's understanding of numerosity and the counting process undergoes change over the course of development

(Beilin, 1975; Court, 1920; Fuson, 1979; McLaughlin, 1981; Saxe, 1977; Schaeffer, Eggleston, & Scott, 1974; Sekular & Mierkiewicz, 1977). This literature, having its origins primarily in the work of Piaget (1965), asserts basically that children's counting comprehension undergoes a transformation from rote recitation to operational understanding between the ages of approximately 2 and 7. For Piaget in particular, counting has no quantitative significance for the very young child and it is not until the child has developed a logical understanding of number that the counting process can be regarded as more than an externally acquired behavior. The second basis for questioning the functional uniformity of gesture in counting over development comes from the research regarding changes in gestural efficiency and will be discussed in more detail later.

The Constructivist Perspective: An Analysis
of the Counting Process

In this view, the process of counting requires that the child set up a series of correspondences between a set of objects and number names such that each and every object is named once and only once. In order to establish that counting is quantitatively meaningful and not merely a mechanical activity, however, the child should use a conventional stably ordered number name list in each count without omitting or repeating any number names. This position is in contrast to Gelman and Gallistel's (1978) views on children's idiosyncratic number lists. They found that these lists were consistent over trials and suggested that their use reflected knowledge of a stable-order principle. They proposed the concept of a principle in search of a list and viewed development as an increase in skill in applying this and the other counting principles. Fuson and her colleagues (Fuson, Richards, & Briars, 1982) work with

young children's number word lists, however, suggested that although children did use unconventional lists consistently, over trials and even over time, only parts of the lists were unconventional. They found that over development the lists changed so that omitted parts of the conventional sequence were filled in. They considered this shift toward conventional usage as evidence against the position that young children understand a stable-order principle. Beilin (1975) also observed that there was a progression in children's ability to use conventional number word lists in rote counting tasks. He found that only 4% of 2-year-olds were able to count to 23, although 44% could rote count to between 7 and 22 without error. Rote counting ability, however, increased rapidly over the next few years so that by kindergarten age, 82% of the children could rote count accurately to 23 and by age 6, 90% could do it.

The use of a stable conventional rather than an unconventional list insures that the child is at least potentially able to attribute a particular quantitative value to each number word. Counting with non-number words or using a list that alters the socially accepted meaning of numerical terms suggests that the child has mastered only the external forms of counting, but does not grasp the quantitative significance of number words. The word or number name has a private meaning for this child which is different from conventional usage. In a sense the child with an unstable or idiosyncratic number name list is engaging in a kind of symbolic activity analogous to the late sensori-motor period child who uses onomatopoeic sounds or words to signify objects and events connected to his/her own activities. As such the use of number words does not include knowledge of the fact that each number name has a consistent value which represents a summation of the values of all

preceding number names and which implies the relative position of that number name in a series of other number names. This knowledge, moreover, is essential for the establishment of a quantitatively significant notion of cardinality.

In order to count meaningfully, the child must be able to express the cardinal value or summation of a count as represented by the final number name of that count. The mere statement of the final number word, however, does not by itself insure that the child understands that the word represents a summation of previous values or their relative positions in the count. The child, therefore, must also be able to use this value as a means of numerically comparing an original set of objects with another set of countable objects. In particular, the child should be able to establish a numerical correspondence between two sets of objects through the utilization of the end product of his/her counting and not merely by means of a perceptual matching of objects between two or more sets.

Based on this description of the counting process, several levels of development of quantitative understanding can be identified and are listed below and in Table 1.

Prequantitative understanding--Level I--Approximately ages 2 to 3. Child knows some number names as distinct from other words, but does not necessarily use number names in a conventional or consistent order beyond 10.

Child does not understand one-one correspondence relations.

Child cannot spontaneously use the final number name of a count to represent the cardinal value (summation) of that count and cannot reproduce a second set that is numerically equivalent to an original set of objects based on the product of that count.

Table 1

Proposed Levels of Development of Quantitative Understanding

Level	Age	Assumed Underlying Competence in Understanding Numerical One-One Correspondence Relations	Performance Variables		
			Distinguishes Number Names from Other Words	Can Count Objects to Cardinal Value	Uses Counting and Cardinal Value in Systematic Approach to Reproduce Set
I Prequantitative	Under 3 years	No understanding	Yes	No	No
II Semiquantitative	4 to 5 years	Incipient but inflexible understanding	Yes	Yes	No
III Fully Quantitative	7 years and above	Flexible and generalizable understanding	Yes	Yes	Yes

Semiquantitative understanding--Level II--Approximately ages 4 to 5. Child knows a stably ordered or conventional list of number names up to and probably beyond the base system range (10 or more).

Child has an incipient understanding of one-one correspondence relations.

Child can spontaneously use the final number name of a count to represent the cardinal value (summation) of that count, but can reproduce a second set that is numerically equivalent to an original set of objects based on the product of his counting, only by means of trial and error.

Quantitative understanding--Level III--Approximately ages 7 to 8. Child knows a stably ordered or conventional list of number names throughout the base system range (beyond 20).

Child has flexible understanding of one-one correspondence relations.

Child spontaneously uses the final number name of a count to represent the cardinal value (summation) of that count and can immediately and systematically reproduce a second set that is numerically equivalent to an original set of objects based on the product of his counting of the original set.

The Relationship of Gesture to the Counting Process

If in fact the above model is accurate and the numerical significance of the counting process is insufficiently understood during early childhood, there is little reason to assume that the very young child is attempting to obtain an accurate count and, therefore, cannot be utilizing gesture toward that end. Rather, it is more likely that as

the child moves from a non-quantitative to a quantitative appreciation of the counting process, the function of accompanying gestures shifts in the same direction. That is, that seeming gestural errors in counting correspond to the natural and appropriate use of gesture in other non-numerical activities and that only as the child's understanding of quantitative relationships develops does gesture take on the specific function of attempting to insure an accurate count. This interpretation is consistent with organismic theory which posits that similar behaviors may serve different functions at different levels of cognitive development and that new and specialized functions evolve from earlier more globally functioning forms of behavior (Langer, 1970; Werner & Kaplan, 1963). The emergence of gesture in counting then should be sought in the early referential-gestural activities of late sensori-motor development and not be viewed as originating in the very act of counting itself.

The Development of the Use of Gesture

The pointing gesture is part of, but by no means the most complex aspect, of the child's system of symbolic thought which begins prior to the onset of language and sometime during the first year of life. It occurs during the sensori-motor period of development and is motivated by the subjective and action-related experience of the child (Piaget, 1962).

Werner and Kaplan (1963) view the pointing gesture as evolving from the infant's reaching to touch movements entailing an outward movement away from the body toward a more distant object. This reaching almost from the start includes a social component in that in order to obtain the object it is necessary to involve another person. The child begins to look away from the object to an adult in order to draw another's

attention to the object of his or her own interest (Bates, Camaioni, & Volterra, 1976).

As the child's early efforts at reaching become increasingly refined, he/she begins to point to more distant objects using a single finger while emitting call sounds (Leung & Rheingold, 1981). According to Werner and Kaplan (1963), these call sounds and gestures emerge together "from a total organismic matrix" (p. 77) and only later become differentiated from one another. Piaget (1962) observes that these call sounds or semi-conceptual verbal schemas involve only a subjective feeling of kinship between the sound emitted and related objects. The call sounds and later semi-conceptual verbal schemas, however, evolve as the child's means of symbolically representing objects apart from their concrete presence. These early verbal forms, though, are to be regarded as changeable symbols, distinct from the fixed meaning of signs determined by the social group. They are part of the development of symbolic thought, originating in motoric activity and separate from language itself which has its own roots in development.

Piaget (1962) observes that somewhere between the ages of 2 and 4 words begin to function as socially determined signs (i.e., language), although they still maintain something of their private meaning in that words continue to constitute a partial substitute for the thing signified and adhere in the object. Nevertheless, at this age words cease to be merely accompaniments to the child's own actions, but provide a beginning for representation in that they evoke an action rather than remain an integral part of it.

The pointing gesture itself, however, remains only a means of denoting or making reference to some concretely present object and does not represent that object (Werner & Kaplan, 1963). With development, though, the goal of pointing gestures ceases to be obtaining an object as it was in its earlier function for reaching to touch. As a means of referencing collective signs or words to objects, directed either to oneself or others, it is part of the child's integration of two separate systems of functioning, that of symbolic thought and language as a system of social signs. It is not until the concrete operational phase of development at approximately ages 7 or 8 that the integration is completed and that verbal concepts are determined by the qualities of objects regardless of whether the child himself or his own activity are also involved (Piaget, 1962). It would follow then that the use of referential pointing gestures in language activities should become increasingly less frequent or necessary as verbal concepts move from the sphere of subjective physical action to that of internalized thought. In a study on verbal learning with children over the age of 8, Dusek (1978) observed that pointing gestures had only a minimal attention focusing effect on performance while verbal labeling itself significantly increased learning of a series of pictures. Nevertheless, the pointing gesture having its roots in the symbolic activities of the late sensori-motor period, serves an important referential function during early language development which precedes the use of gesture in a counting context.

The Development of the Use of Gesture in
Counting and Related Activities

The pointing gesture when used in conjunction with early counting activity at about age 2 or even younger may reflect the non-numerical way of referencing words to objects described above. As such it would be an extension of the function of pointing and labeling used in other verbal activities and as yet have no specialized numerical function. In this form it cannot be considered an ineffective or uncoordinated means of insuring an accurate count, but rather an appropriate and even skillful adjunct to another naming activity (i.e., referencing a word to an object).

Just as the child points in order to reference non-numerical words to objects before collective language becomes integrated with symbolic thought, he/she may point in order to reference number words to objects in a non-quantitative way before doing so for a quantitative purpose in counting activities. Fuson (1979) points out that as in early non-numerical labeling, the young child's series of number names consists of a relatively undifferentiated segment recited as a single word rather than as a series of elements each referring to a particular object. Saxe (1977) observes that very young children sometimes use a sweeping gesture when counting objects with no single gesture attaching a particular object to a particular number name. Rather the gesture refers to a group of objects and may be accompanied by one or more names. The gesture itself, then, is first utilized as part of a number naming activity in which number words are not yet imbued with collective quantitative meaning but whose meaning adheres in the object or objects to which they refer.

Gelman and Gallistel (1978) report that the preschool counters they observed did not exhibit evidence of believing that number names were fixed to particular objects. Rather in testing for their "order-irrelevance principle" they found that 3- and 4-year-old children, but not 2-year-olds, could assign any number name to any object when arrays were counted repeatedly. However, they also found that many of the children were rigid in establishing positions for number names. That is, the third object in an array could be called number one, but only after it had been moved to the first position in the row. This suggests that in early counting activities it may not be the object itself that is named, but rather that the number name adheres in a particular place or position. In contrast to Gelman and Gallistel's observations, Ginsburg (1977, 1982) cites anecdotal evidence that supports the notion that when very young children count a set of objects, the recitation of number words amounts to giving a name to each object. These names, like other non-numerical names, are then considered to be part of the objects to which they are assigned. He reports on a 4-year-old who was having tea and bread with her governess. The child correctly counted "one, two, three" pieces of bread, ate one piece, and was then asked how many pieces there now were. She said, "three," because even though she had eaten one, "two and three" were left. In a similar context, the present investigator observed her 2-1/2-year-old daughter counting a heterogeneous array of four objects. As the child pointed to each object in turn, she said, "This is one [a cup]. This is two [another cup]. This is six [a pitcher]. This is eleven [a strawberry]. No, this is a cup. This is a different cup. This is a pitcher. This is a strawberry. No, this is one [a cup]."

This is six [another cup]. This is one [a pitcher]. This is two [a strawberry]." Such behavior illustrates an instance in which number names were used interchangeably with non-numerical names and did not represent quantities. In this case the pointing referenced these names to objects rather than assisted the child in keeping track of objects already counted. Although all children do not produce this type of counting, such observations suggest a way of understanding the covert processes of other very young children who appear to be counting and using number words in more conventional patterns.

Steffe, Richards, and von Glaserfeld (1979) refer to this non-quantitative level of counting as Rote Counting in which the first few number names may be uttered in sequence but without any understanding that this sequence can or should be said in synchrony with some other sequence of events. They believe that this type of counting provides a language base for other types of counting, but in this form should be considered to be part of the province of language and not mathematics. With development there tends to be an increased synchrony between the utterance (number name) and the object to which it refers. There is not, however, necessarily a correspondence between the number of utterances (number names) and the number of objects to be counted.

The transformation of the pointing gesture into a specialized numerically significant activity would depend on the child's development of quantitative understanding in general. Such progress in quantitative understanding is evidenced in the older child's increased consistency in counting accuracy (Fuson & Mierkiewicz, 1980; Ginsburg & Russell, 1981; Shannon, 1978), ability to use the product of a count as a representation

for array size (Russac, 1978; Schaeffer et al., 1974), and ability to establish equality of set sizes through the construction of one-one correspondences (Piaget, 1965). These quantitative capacities, however, are only partially developed in the young child initially and, therefore, limited by particular task variables. Increasing set size, for example, has a deleterious effect on every aspect of quantitative understanding at this level and can reduce the child to strategies, inaccuracies, and inconsistencies found at previous levels (Fuson, 1979; Fuson & Mierkiewicz, 1978; Gelman & Gallistel, 1978; Schaeffer et al., 1974; Shannon, 1978; Silverman & Rose, 1980).

Nevertheless, with this increased quantitative understanding the gesture should shift in function to aid in providing a means of insuring an accurate count. As Werner and Kaplan (1963) point out, "an organism, initially realizing a novel function through operations which subserve other, more primitive ends, eventually 'creates' or 'shapes' a more specialized, function-specific means for the execution of the novel end" (p. 80).

As gesture takes on a quantitative rather than referential function, it becomes a central activity in the counting process serving to partition, keep track of, and organize the objects to be counted. This central role of gesture in the counting process is further emphasized by Siegler and Briars (1981) who found that a large proportion of their 5-year-olds as compared to younger children regarded the one-one correspondence of points to objects as an essential feature for counting accuracy. The tracking and partitioning function of gesture then should serve to promote more accurate counts than when gesture is not utilized (Saxe, 1981; Saxe & Kaplan, 1981).

Unlike the transformation of the use of gesture in the counting process, the function of gesture in non-numerical activities may remain constant at the level of partial quantitative understanding and continue to serve a referential and not a partitioning function. This would be because number words, unlike other words whose meanings are more specific and consistent across different contexts, are not bound to any particular external referents. Therefore, they are more readily separated from the objects to which they refer. The solely referential use of gesture in counting activities, then, is likely to persist for a shorter period of time than it does in other non-numerical labeling activities. That is, because number words are not consistently bound to particular objects as compared to non-numerical words, referencing number words to objects should become increasingly irrelevant as quantitative understanding of the number words develops. In a sense, this distancing between number word and object is similar to the general language development of bilingual children in that these children learn early on that the same object can be referred to by different names. Such development has been found to facilitate more flexible thinking in the child (Saxe, Sicilian, & Schonfeld, 1980).

Another possible approach to understanding the earlier separation of number words from objects as compared to other types of words arises from Gelman and Gallistel's (1978) work on the order-irrelevance principle. Their evidence indicated that there was less connection between number word and object than between number word and position for 3- and particularly 4-year-old children. This suggests that pointing in counting involves signifying places for children whose quantitative

understanding is beginning to emerge. Pointing to reference places naturally leads to keeping track of positions in the context of a series of objects. Such dominance of position over objects themselves does not occur in non-numerical labeling tasks. Therefore, pointing in order to reference words to objects rather than to keep track of objects already labeled should persist over a longer period of development in labeling than in counting activities.

On the other hand, it is also possible that as the child develops an incipient understanding of one-one correspondences in a counting context, that this knowledge may be applied to non-counting contexts as well (Flavell & Wohlwill, 1969). That is, a child may be able to exhaustively label a group of objects by means of attaching a single non-numerical name to each and every object. This process, however, requires only that the child label one object at a time and then another one and another one without regarding each word as a summation of all objects previously labeled. Pointing at this level, therefore, may be utilized as an aid for separating labeled objects from yet to be labeled objects.

The literature indicates that by the time that the child appreciates quantitative relationships in the sense that Piaget (1965) attributed to his Stage III or operational subjects, the importance or reliance on overt tracking gestures in order to facilitate an accurate count should decline and be used only on larger or less orderly sets lacking perceptual supports if at all (Beckwith & Restle, 1966; Saxe & Kaplan, 1981; Schaeffer et al., 1974) and then not necessarily in the form of one-one pointing gestures. This movement away from overt pointing gestures is consistent with the child's shift away from active motoric expressions

of intelligence to internal cognitive operations (Piaget, 1976). Gestures then should tend to be covert (i.e., eye movements, head nodding) and most often utilized as a means of partitioning parts of arrays into segments for possible addition or multiplication operations used in obtaining a judgment of numerosity (Beckwith & Restle, 1966).

It is only after having developed a completely operational understanding of quantification in a counting context, that the child should be able to generalize these numerical grouping strategies to non-counting tasks. The referencing function would no longer apply here since pointing to individual members would become less important than partitioning segments into numerically more manageable groupings. On non-numerical labeling activities, therefore, gestures when used should serve the same partitioning function as when utilized in counting activities (Elkind & Weiss, 1967). It should be noted that although other grouping strategies based on classification of object properties or functions may precede numerical partitioning in non-numerical labeling activities, this type of strategy does not serve the same quantitative function of keeping track of each and every object until numerical one-one correspondences are understood.

Counting Accuracy and the Use of Gesture

The second basis for questioning the functional uniformity of gesture utilization in counting activities comes from evidence regarding the development of the use of gesture in counting activity both in terms of the decrease in errors of execution and the evolution of more efficient pointing strategies over development. Gestural errors or the child's failure to maintain a one-one correspondence between each pointing

gesture and external object while reciting a single number name has been observed in virtually all studies of young children's counting behavior (Gelman & Gallistel, 1978; Klahr & Wallace, 1975; Schaeffer et al., 1974). From the maturationist point of view these errors merely reflect a problem in motor coordination or lack of practice and not a cognitively less mature interpretation of the task at hand. The child here is always attempting to use pointing gestures to keep track of and separate objects counted from those yet to be counted. Nevertheless, such errors have been found to be reduced in the performance of older children indicating some sort of change in the use of gesture over development that may suggest a shift in gestural function as well as improved motor coordination.

In a recent study by Saxe and Kaplan (1981) which examined the use of gesture at different age levels, evidence was found suggesting that pointing gestures themselves, even when used in the counting process, are not necessarily used for the purpose of insuring an accurate count. In this study 2-, 4-, and 6-year-old children were asked to count pictures of animals ranging in set size from 2 to 9 under conditions in which gesturing was or was not allowed. Gesturing was inhibited by having children hold onto a cardboard box, representing a cage for the animals, as they counted the pictures on view inside the box. The results of this study indicated that only 4-year-old children whose counting abilities were beginning to emerge, but whose skills were not yet perfected, benefitted in accuracy from the use of pointing gestures on the larger set sizes. The younger children, however, made as many counting errors under conditions in which pointing was or was not allowed

and older children tended to use few gestures on smaller set sizes suggesting that a uniform function for pointing gestures in counting should not be assumed at all levels of development.

Interestingly, coming from a different perspective, Gelman and Meck (1983) found essentially the same results regarding the use of gesture in counting. Although they were seeking evidence to demonstrate that performance demands can mask the young child's implicit knowledge of counting principles, their results were not inconsistent with the position supporting a developmental shift in the function of gesture in children's counting activities. In their study 3- and 4-year-old children were asked to count the same three-dimensional objects twice. On one condition they were allowed to touch and move the items and on the other the objects were shielded by a sheet of plexiglass so that they could not be handled. Gelman and Meck found that the older, 4-year-old, children were able to maintain accurate counting on small set sizes with or without the use of gestures. As set size increased, however, these children also became inaccurate counters on the plexiglass no-gesture condition.

In a study with blind children and sighted controls, Sicilian (1985) found a similar pattern of development for the function of gesture in counting. His subjects were presented with collections of blocks of set sizes 7, 8, and 9. On half the trials the blocks were fixed on sheets of plywood which prevented the children from relocating the objects during a count. On the other half of the trials, the blocks were placed in a shallow box and subjects were allowed to move them during a count. Both fixed and loose arrays were presented in linear,

circular, and random patterns. The linear and circular arrays were always homogeneous in block shapes while half of the random arrangements presented consisted of heterogeneously shaped collections of blocks. Blind subjects were rated on levels of counting scanning and organizing strategies. Sicilian's results indicated that only those blind children who were assessed as having a partially developed strategy for scanning, organizing, and partitioning objects appeared to benefit from the use of gesture on small moveable arrays. In contrast, subjects at both the highest and lowest levels of scanning strategy efficiency were no more accurate in counting moveable arrays than they were in counting fixed arrays. As with sighted children, the poor counters remained inaccurate regardless of the opportunity to utilize gestures for keeping track of objects in a count and the good counters remained accurate regardless of whether only subtle or more overt gesturing was permitted.

The Development of the Efficiency of Gestural Strategies in Counting

In terms of evolving more efficient pointing strategies, it has been found by several investigators that as children's counting accuracy increases, their patterns of gesturing undergo systematic change progressing from less orderly to more orderly forms. In a study involving counting checkers arranged in columns and rows, Shannon (1978) was able to identify three types of strategies used by children between the ages of 3 and 6. At the first level children tended to count items based on their proximity to one another. Next children tended to outline the form of the array (i.e., count around the periphery) before counting the interior items, and finally, older children used a linear strategy in

which objects in columns or rows were pointed to in succession. Similar strategies were observed earlier by Potter and Levy (1968) who also identified a more primitive phase in which children's pointing patterns were dominated by object interest and saliency. At the other extreme, using older subjects, Beckwith and Restle (1966) described a form of "pointing" strategy often involving covert tracking rather than overt gesturing. This covert strategy entailed the use of grouping sections of an array which were counted separately and then added or multiplied mentally in order to determine the total number of objects. Interestingly, on tasks with children ranging from 4 to 9 years old involving labeling instead of counting pictures of objects, Elkind and Weiss (1967), Gottschalk and Bryden (1964), and Kugelmass and Lieblich (1970) found the same kind of age-related decrease in unsystematic order of naming patterns and a comparable age-related increase in organized patterns. As in the counting studies, the more systematic patterns were associated with fewer omissions and repetitions of picture names. These findings have usually been interpreted in terms of the development of perceptual organization or as a function of the effect of learning to read. It seems equally plausible, however, to view this increase in the systematic use of gesture in terms of an interaction between perceptual development and an increase in quantitative understanding of the counting process. That is, to the extent that the child appreciates the necessity of labeling each object once and only once, he can use gesture systematically to exhaustively label a collection of objects.

CHAPTER II

Statement of the Problem

The purpose of this study was to examine the way in which the function of gesture in the counting process varied over development, was related to the use of gesture in other non-numerical language activities, and interacted with the child's level of quantitative understanding. The following model provided the basis for investigation.

Summary of the Development of Quantitative Levels and
Their Relationship to the Functional Shift in Gesture

Three developmental levels of quantitative understanding as they relate to the counting process were distinguished for children between the ages of approximately 2 and 8 as follows:

Level I--Prequantitative Understanding
(Between Ages 2 and 3)

Child knows some number names.

Child does not understand one-one correspondence relations.

Child cannot reproduce a set based on cardinal value of counting.

Level II--Semi-quantitative Understanding
(Between Ages 4 and 5)

Child knows number names in stable or conventional order.

Child has incipient understanding of one-one correspondence relations.

Child can reproduce a set based on cardinal value of counting by trial and error only.

Level III--Quantitative Understanding
(Between Ages 7 and 8)

Child knows number names in stable or conventional order.

Child has flexible understanding of one-one correspondence relations.

Child can reproduce a set immediately and systematically based on cardinal value of counting.

One of the basic assumptions of this study is that very young children, ages under 2 to about 3, who use pointing gestures in counting activities do so in order to reference a word or group of words to some object or objects and not to partition or keep track of objects already counted. This referential function of gesturing while counting is seen as equivalent in purpose to the kind of gesturing that accompanies tagging objects with non-numerical labels. It is viewed, therefore, as originating in sensori-motor activities and as an integral part of early verbal behavior. The occurrence of such gesturing, then, should be pervasive and independent of any array specific properties of stimuli such as set size or spatial configuration. Gesturing in this referential context is not considered to have any effect on whether or not each object is labeled once and only once and, therefore, performance should not differ between conditions in which children are or are not allowed to use gestures.

It is further assumed that with the development of numerical understanding there is a shift from the referential function of gesture to its use as a partitioning and tracking aid in counting activities. During the period in which this transition is taking place there should be a marked increase in counting accuracy when gestures are utilized. There

should be a similar tendency toward fewer omissions or repetitions on non-numerical labeling tasks to the extent that the partitioning function of gesture can be adapted to other situations in which one-one correspondences are appropriate. Because gesture during this transitional period in counting functions in a specialized form distinct from its origins as an accompaniment to verbal utterances, the interaction between gesture and utterance becomes a more complicated one. Moreover, because the development of a specialized form to serve a new function does not proceed abruptly or become complete at once, this new interaction needs time to become coordinated and automatic. Task variables, therefore, should have an effect on the degree to which this shift in function will be manifested. In particular, arrays that offer some perceptual supports for tracking objects should lend themselves more readily to the specialized use of gesture as an aid to counting accuracy. As a result, accuracy in counting smaller and/or linear arrays with the use of gesture should improve earlier than accuracy for larger and/or disorderly arrays. To the extent that pointing as a tracking aid has been adapted to non-numerical tasks, the same effect of array configuration should be observed.

As children develop a greater understanding of quantitative relationships, and with this an ability to track objects covertly, they should employ overt gestures primarily in situations that lack obvious perceptual supports such as those consisting of larger set sizes or disorderly arrays. It is further assumed that children who have developed a mature understanding of numerosity will recognize opportunities to apply partitioning aids to situations that do not specifically call for

numerical assessments. That is, they may utilize a counting gestural strategy to group or reorganize objects to partition objects already named from those yet to be named in a non-numerical labeling task.

Basic Methodology

In order to test the model outlined above, a study was designed in which children between the ages of 2 and 8 were given an opportunity to count and label objects under conditions in which gesturing was and was not permitted. The children were first assessed on three quantitative tasks in order to determine their levels of quantitative understanding. All children were then given two series of counting tasks involving three-dimensional heterogeneous arrays of objects of varying set sizes in both linear and disorderly arrays. On one series of tasks the children were allowed to use gestures while counting and on the other they were prevented from using gestures. They also received two comparable tasks in which they were asked only to name all the objects in an array. These labeling tasks included the same gesture and no-gesture conditions. Labeling and counting tasks were counterbalanced as were the gesture and no-gesture conditions.

The independent variables under investigation were age as an indicator of quantitative development, set size, array configuration, task context (counting or labeling), and gesture condition (with or without). The dependent variables on which children were assessed on both gesture and no-gesture experimental conditions were counting or labeling accuracy as measured by the correspondence of names uttered to objects present, whether or not gesturing occurred, and the time taken to complete each counting trial. The dependent measures for the

gesture condition only were the number of gestures used, the spatial patterns of gestures observed, and the gestural techniques utilized on each trial. Children were interviewed at one testing session whenever possible.

Hypotheses

The main purpose of this study was to examine the way in which the function of gesture in the counting process varied over development and interacted with the child's level of quantitative understanding. A basic assumption, however, was that quantitative level was closely related to age and that even though age itself was not a causal factor of developmental change, it would be a useful predictor of quantitative level.

Hypothesis 1

As illustrated in Figure 1, it was hypothesized that quantitative level scores would be positively correlated with age such that children between the ages of 2 and 3 would tend to be at Quantitative Level I, children between the ages of 4 and 5 would tend to be at Quantitative Level II, and children between the ages of 7 and 8 would tend to be at Quantitative Level III.

Hypothesis 2

The second hypothesis was concerned with whether gesturing did or did not occur at the different age levels and the relationship of the extent of occurrence to the function of gesture. This concern was based on the conception that the referencing function of pointing gestures has its roots in the sensori-motor period of development and, therefore, is an important part of the young child's verbalizations. The young child frequently uses gestures when referencing verbal labels to objects.

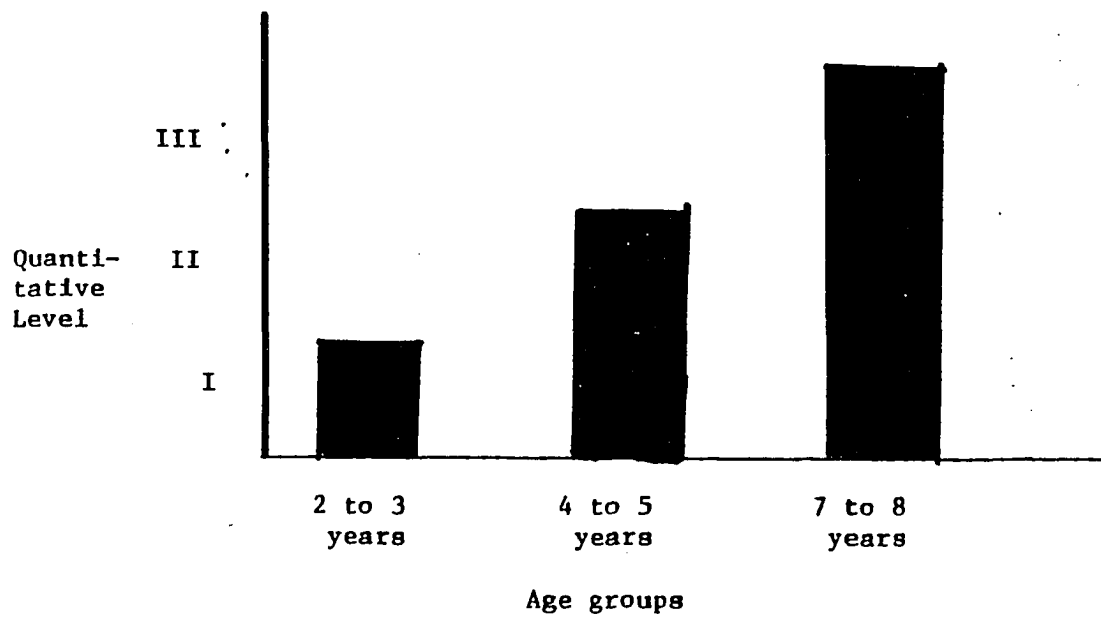


Figure 1. Hypothesized relationship between age and quantitative level.

Because it was hypothesized that the young child uses gesture for this same referencing purpose when counting, it was expected that he/she would gesture as frequently in a counting context. As quantitative understanding develops, however, it was hypothesized that the use of pointing gestures would shift in function for counting activities from that of referencing to tracking and partitioning and that this shift in function would follow to some extent in other forms of verbal labeling activity (see Hypothesis 8). It was expected, therefore, that over development as the use of pointing gestures became less tied to verbal activities and more connected to quantitative reasoning, gesturing would become less pervasive and more dependent upon the nature of array configuration and set size, and in particular whether gesture was allowed or prohibited. The use of pointing gestures then would be pervasive in the counting and labeling activities of prequantitative children, but less frequently observed in counting and labeling activities as children's quantitative understanding increased.

As Figure 2 illustrates, it was hypothesized that within the counting and labeling conditions, there would be a significant interaction effect between age and/or quantitative level and the occurrence of spontaneous pointing gestures such that 2- to 3-year-old children would use pointing gestures on more trials than 4- to 5-year-old children and that 4- to 5-year-old children would use gestures on more trials than 7- to 8-year-old children.

Hypothesis 3

The third hypothesis concerned the relationship between the number of names to gestures correspondence and the gesture to objects

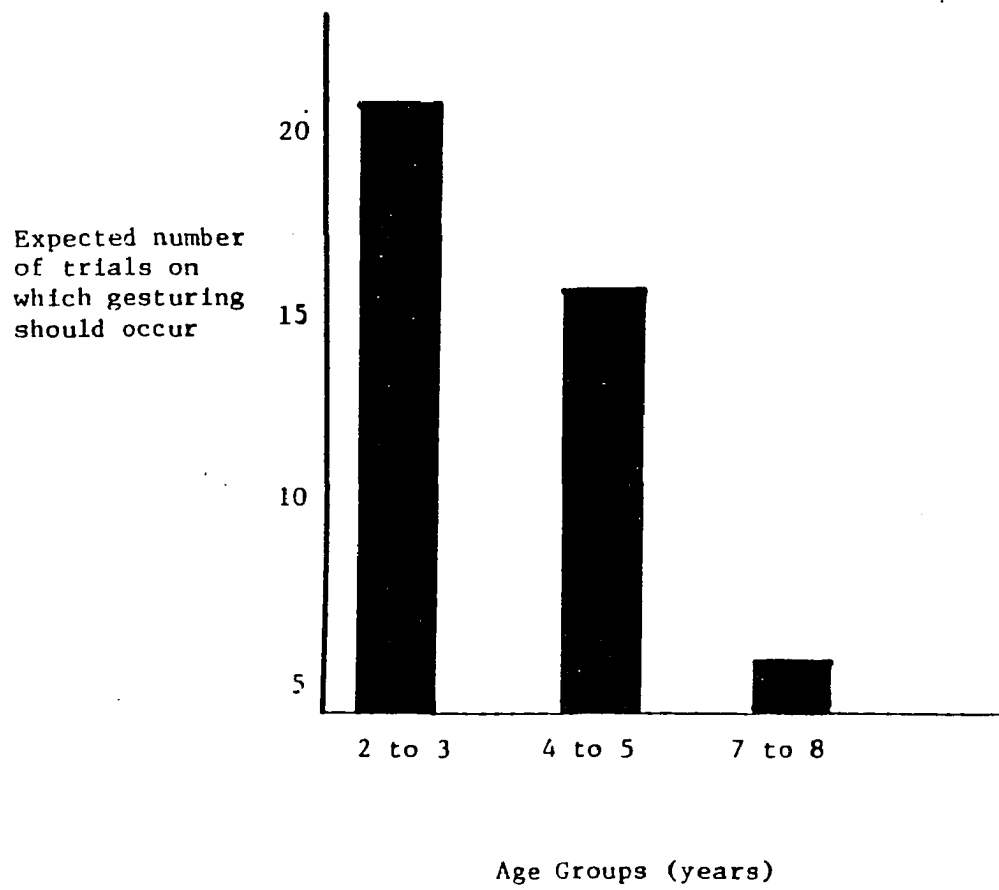


Figure 2. Hypothesized frequency of occurrence of gesturing within either counting or labeling condition.

correspondence. During the earlier phases of counting development it was hypothesized that children did not use gesture to insure an accurate count, but to reference individual or groups of number names to objects in an array. Because children at a prequantitative level of development would not understand the necessity of establishing one-one correspondences between each number name and object, there would be no reason for them to point to each object once and only once. On the other hand, there should be a close relation between verbalizations and referencing gestures and so one would expect to find a close correspondence between the number of gestures and number of words utilized in any count or labeling activity. As children begin to develop a greater understanding of one-one correspondence relations, the discrepancy between the number of gestures utilized and the number of objects counted or labeled would be expected to diminish and thus be more in proportion to the correspondence of names and gestures.

As Figure 3 illustrates, it was hypothesized that on both counting and non-numerical labeling tasks there would be a significant interaction effect between age and/or quantitative level and the correspondence of number of names, objects, and gestures such that there would be a greater numerical correspondence between the number of gestures and names used than between the number of gestures and objects in an array for 2- to 3-year-old children only.

Hypothesis 4

The fourth hypothesis concerned the effect of gesture condition on counting and labeling accuracy. Because gesture was hypothesized to serve only a referential and not a partitioning function in early

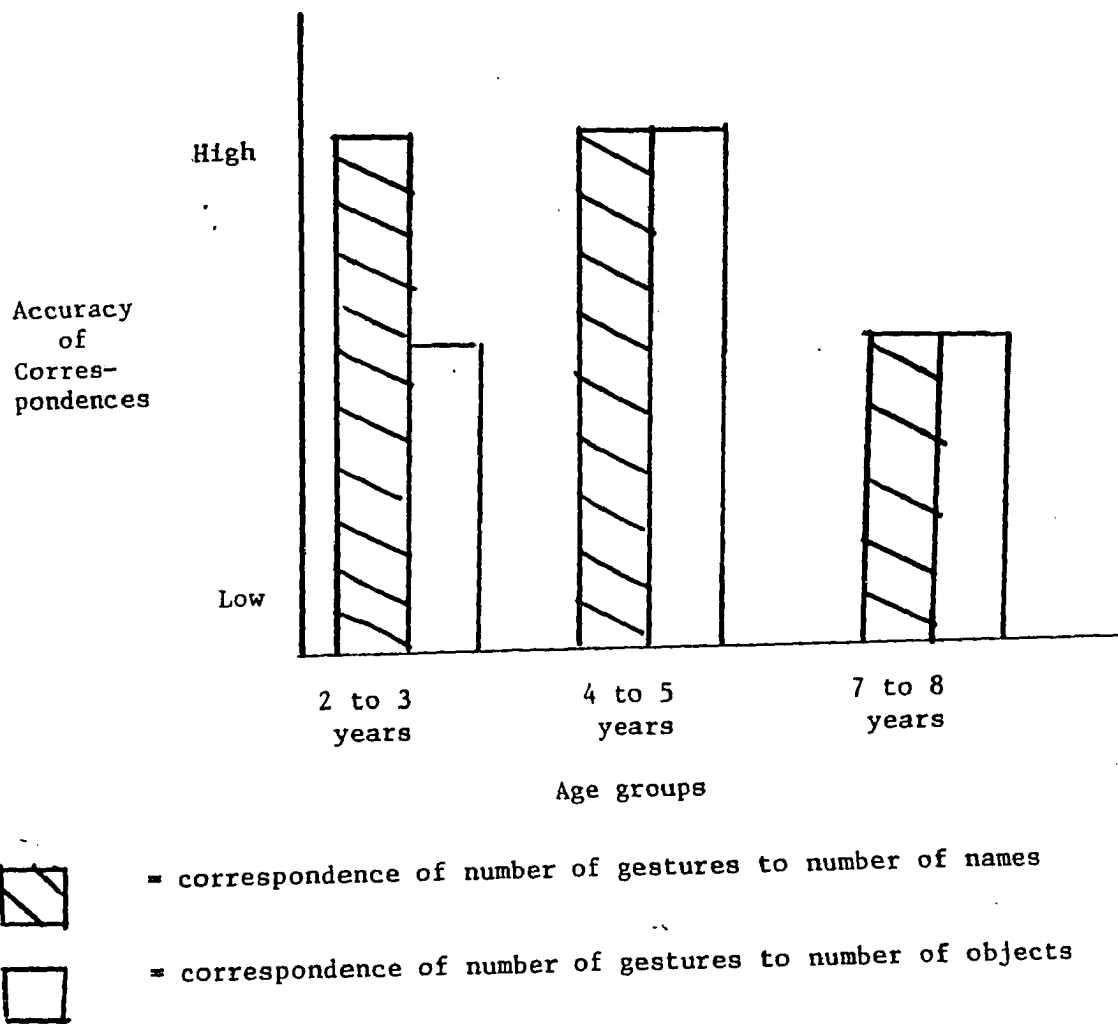


Figure 3. Hypothesized accuracy of correspondences.

counting activity, it was expected that for children at the earlier levels of quantitative development, the use of gesture would not produce a more accurate count than when gesture was not utilized and that they would count inaccurately under all conditions. In contrast as counting began to take on a quantitative meaning, overt gesturing would facilitate the child's partitioning of objects already counted from those yet to be counted at all set sizes (with the possible exception of set sizes within the perceptual or subitizing range, i.e., 2 or 3). Therefore, counting accuracy for these children should be greater when gesturing was permitted than when it was not. In addition, as children attained a fully quantitative understanding of counting, although the use of overt gesture for facilitating an accurate count might become less necessary, it should still apply to very large set sizes and irregular or disorderly array configurations in which covert tracking became too difficult. Thus, for children at the highest level of quantitative development, counting accuracy should be facilitated by gesturing for large and/or disorderly arrays. It was expected that comparable changes in accuracy with gesture would be observed on non-numerical labeling tasks as well.

As Figure 4 illustrates, it was hypothesized that there would be a significant interaction effect between age and/or quantitative level and gesture condition such that 4- to 5-year-olds and, to some extent, 7- to 8-year-old children would count and label more accurately under the gesture as compared to the no-gesture condition and that no difference in counting or labeling accuracy would appear for 2- to 3-year-old children between gesture conditions.

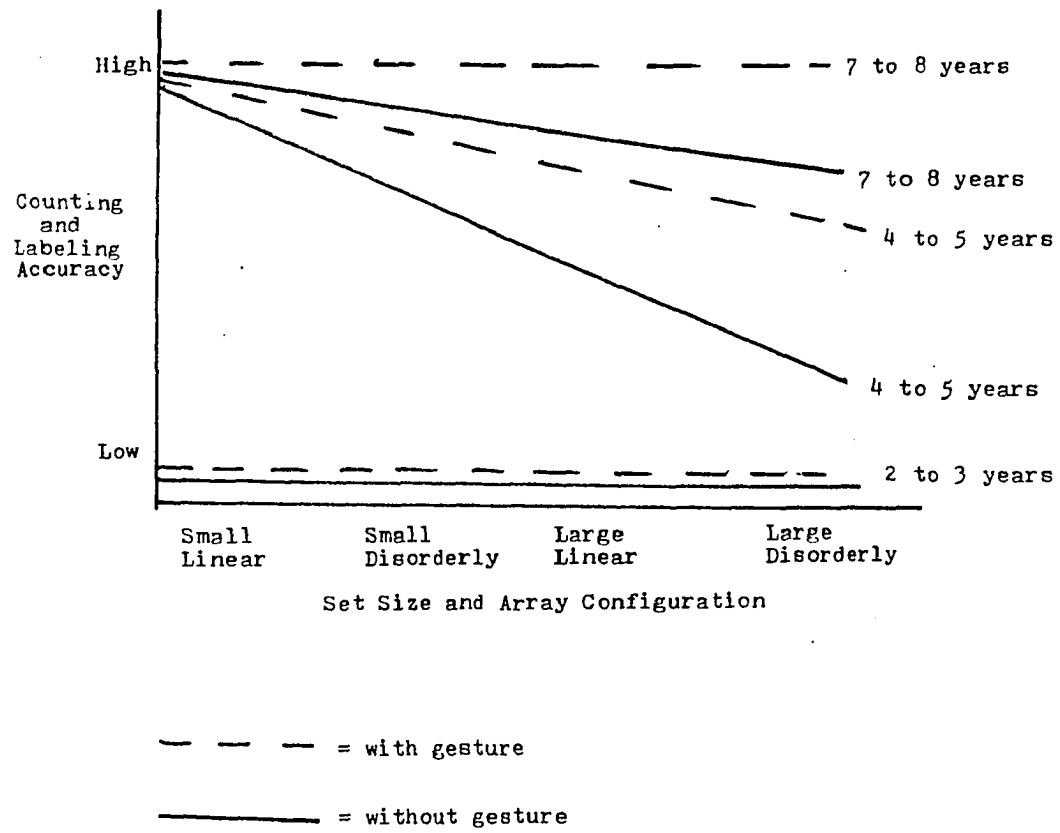


Figure 4. Hypothesized counting and labeling accuracy and gesture condition.

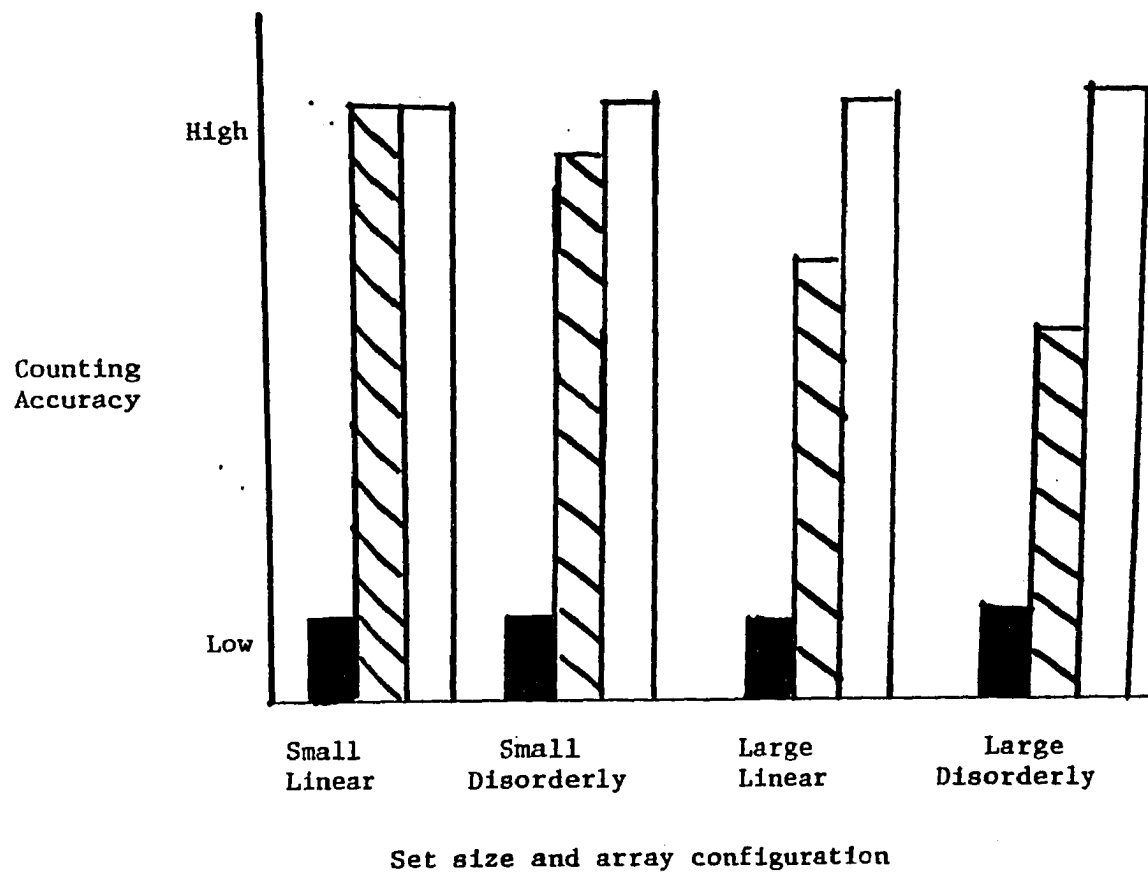
Hypothesis 5

The fifth hypothesis concerned the effect of array parameters on counting and labeling accuracy. Because the development of quantitative understanding of the counting process evolves gradually, there should be a transitional level of understanding in which array parameters should affect counting accuracy even with the use of gestures. Counting accuracy should first be attained for smaller and linear sets and only later should accuracy be as consistent on larger and disorderly arrays. It was not expected that array size and configuration would have this effect on children with non-quantitative abilities or children with a fully developed quantitative understanding of counting. To the extent that counting knowledge could be applied to non-numerical labeling tasks, the same effect was expected.

As Figure 5 illustrates, it was hypothesized that within the counting and labeling gesture conditions, there would be a significant interaction effect between age and/or quantitative level and array parameters such that only 4- to 5-year-old children would count more accurately on linear and/or smaller arrays than on larger and/or disorderly arrays.

Hypothesis 6

The sixth hypothesis was concerned with the amount of time taken to complete tasks. Because gesturing when used referentially is closely tied to verbalizing, it was expected that gesture and verbalization in this context would occur essentially simultaneously. When gesture was used for purposes of partitioning, however, it was expected that additional time would be required to complete tasks. This is because the partitioning itself has a function independent and beyond the simple



- = 2 to 3 years
- ▨ = 4 to 5 years
- = 7 to 8 years

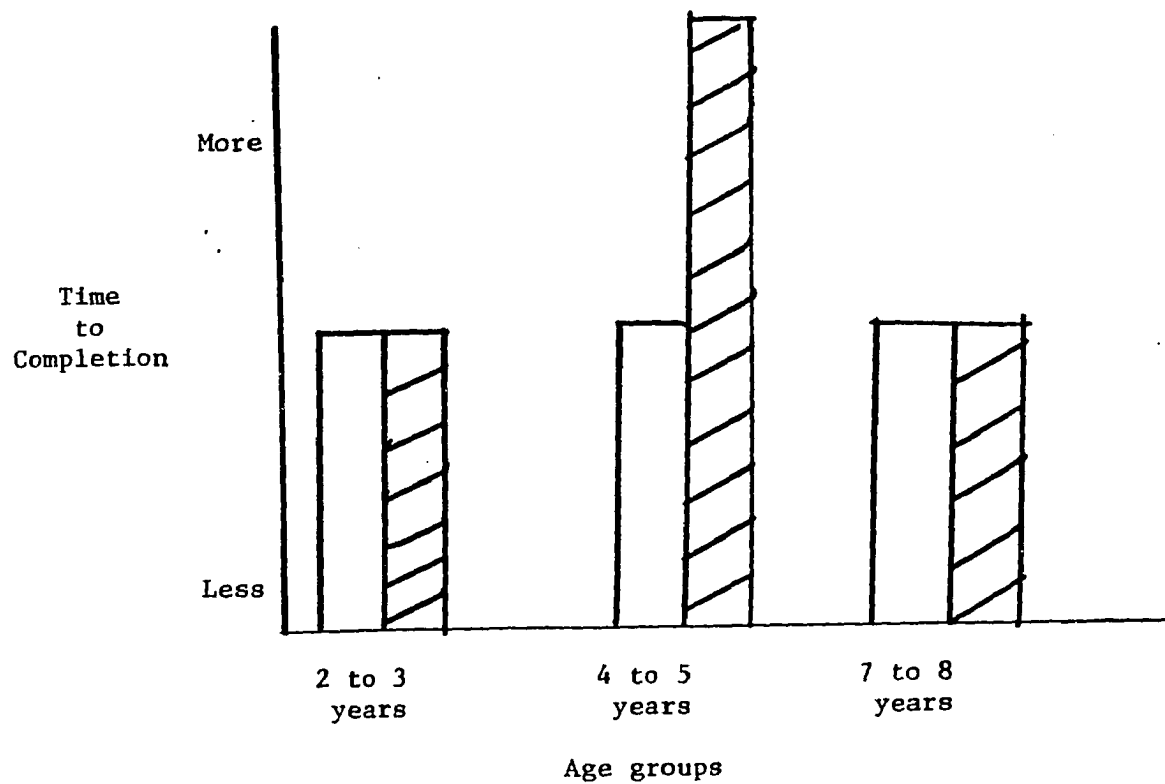
Figure 5. Hypothesized counting accuracy and array specifications under gesture condition.

act of labeling an object. In particular, when this function is serving an incipient quantitative understanding, the time taken to complete the task should be extended. This is because at the level of incipient understanding, gesturing should be necessary to obtain an accurate count and, therefore, warrant sustained effort. Without the use of gesture, however, children would tend to become frustrated and lose sight of the necessity of maintaining a one-one correspondence between number names and objects. Therefore, counting without overt gestures should not involve serious covert gesturing efforts and so take less time to complete. As quantitative understanding becomes consolidated, the partitioning function of overt gesturing should not involve any more effort than the partitioning function of covert gesturing which was expected to predominate and be utilized when overt gestures were prevented. Therefore, at this level if overt gesturing was used, it should not have taken any longer to do a task than under conditions in which overt gesturing was not permitted.

As Figure 6 illustrates, it was hypothesized that there would be a significant interaction effect between age and/or quantitative level and the time taken to complete a count such that the amount of time taken to complete the task with gestures than without gestures would be greater for 4- to 5-year-old children, but not for 2- to 3- or 7- to 8-year-old children.

Hypothesis 7

The seventh hypothesis concerned the efficiency of gestural patterns used. Just as counting accuracy increases over development, gestural strategies increase in efficiency over development. Younger children



□ = no gesture

▨ = gesture

Figure 6. Hypothesized relationship between time taken to complete counting task and gesture conditions.

should tend to use more random, hit and miss orders of pointing, while older children should become more systematic in the order in which they point to objects in an array. In general, more efficient gestural patterns should be associated with greater counting accuracy. It was expected then that these increases in efficiency and accuracy would be related to the function of children's pointing gestures and to levels of quantitative understanding or age.

As Table 2 indicates, it was hypothesized that within the counting gesture condition, there would be a significant interaction effect between age and/or quantitative level, counting accuracy, and type of gestural strategy pattern utilized such that particular patterns and less counting accuracy would be associated with the referential function of gesture at ages 2 to 3 and other patterns and greater counting accuracy would be associated with the partitioning function of gesture at ages 4 to 5 and 7 to 8.

Hypothesis 8

The eighth hypothesis concerned the adaptation of quantitative gestural techniques to non-quantitative domains. Once the child develops quantitative understanding of counting and has developed some efficiency in using gesture to aid in obtaining an accurate count, he/she should be able to adapt this gestural technique to new situations that do not specifically demand a quantitative approach, but which could benefit from one. This adaptation would be reflected in a new use of gesture in non-numerical labeling tasks in order to help insure that all objects have been labeled once and that none had been repeated. The referential function of gesture then would be subsumed by a numerical

Table 2

Hypothesized Relationship of Age (and Quantitative Level) to Gestural Function, Gestural Strategy, and Counting Accuracy

Age in Years (Quantitative Level)	Gestural Function	Gestural Strategy	Accuracy Counting
2 to 3 (I)	Referential	Random	Poor
4 to 5 (II)	Partitioning	Orderly Non-linear	Fair
7 to 8 (III)	Partitioning	Linear	Good

partitioning function manifested in object reorganizations and partitioning by groups. These strategies should not be observable in the non-numerical labeling gestural techniques of children who had not yet reached levels of full or at least partial quantitative understanding of the counting process.

It was hypothesized that within the non-numerical labeling gesture condition, there would be a significant relationship between age and/or quantitative level and gestural technique such that 7- to 8-year-old children would have a greater frequency of occurrence of numerical gestural techniques (such as object reorganizations or partitioning by groups) than 2- to 3- or 4- to 5-year-old children.

CHAPTER III

Method

Subjects

Sixty children were interviewed at each of three age levels. The youngest group consisted of 2- and early 3-year-olds in pre-nursery school (range = 2 years, 5 months to 3 years, 5 months; mean age = 2 years, 11 months; S.D. = 3.03 months). This group will be referred to as the 3-year-olds. The middle age group consisted of 4- to 5-year-old nursery school children (range = 3 years, 11 months to 5 years, 3 months; mean age = 4 years, 6 months; S.D. = 5.61 months). This group will be referred to as the 4-year-olds. The third and oldest group consisted of second and third grade children between the ages of approximately 7 and 8 (range = 6 years, 11 months to 9 years, 0 months; mean age = 7 years, 9 months; S.D. = 6.86 months). This group will be referred to as the 7-year-olds. Each group contained 20 subjects, with approximately equal numbers of boys and girls. Children were selected from middle class private schools in the New York City area.

Materials

Two sets of materials were used. For the pretest a small toy drum, a 5 x 9 cm matting board with seven nickels evenly spaced and pasted on, a lidded cigar box into which the board with nickels fit, a 5 x 10 cm matting board with nine pennies evenly spaced pasted on, and a collection of 25 loose pennies were used.

For the experimental task 48 miniatures of common objects, 10 30 x 60 cm matting boards, a 30 x 60 cm. wooden platform on non-moveable wheels with handles on each side of the platform, and a Sesame Street Big Bird finger puppet were used. Table 3 contains a list of the miniature objects used.

Heterogeneous collections of objects were utilized in order to make counting tasks as comparable to labeling tasks as possible. See Siegel (1973, 1974) for a discussion of the effects of array heterogeneity on counting accuracy. Linear and disorderly displays were counterbalanced in order to study more closely the effect that array configuration had on counting performance. See Siegel (1972, 1973, 1974) for a discussion of the effects of spatial arrangements of arrays on numeration ability. Three-dimensional objects rather than pictorial representations of objects were utilized because the former have generally been found to be more salient, particularly in directing action of children below age 7 (see Cocking & McHale, 1981; Daehler, Perlmutter, & Myers, 1976; Daehler, Lonardo, & Bukatko, 1979; Klapper & Birch, 1969) and because they lend themselves more readily to the child's natural use of pointing gestures and object manipulation.

Procedure

Subjects were seen individually in their schools or at the experimenter's home. Each child was seated at a table next to the experimenter and given a 5-minute warm-up period during which time he/she had an opportunity to become comfortable with the experimenter and, particularly in the case of the younger children, to play with the finger puppet and objects similar to the ones used in the experimental tasks. This play

Table 3

List of Common Objects Used in Experimental TasksSample Items

rocking horse

shoe

Trial Items

apple	crayon	mile bottle
baby bottle	cup	mirror
baby doll	egg	necklace
banana	eye glasses	orange
bandaid box	fire hat	paint brush
barrette	flower	pants
book	fork	pencil
boot	glass	plate
camera	grapes	raisin box
candle	guitar	ring
car	hair brush	scissors
carrot	hanger	shirt
cereal box	key	soda bottle
cheese	knife	spoon
comb	ladder	telephone
corn	lamp	television

period was intended to reduce the child's curiosity and task irrelevant behaviors during the actual task administration.

During the piloting phase of the study each experimental object was also held up by the experimenter and children of all ages were asked to identify each of the objects. This was to eliminate any objects which may have been too difficult to recognize or label before the actual data collection began. In addition, the first item of all testing sessions was a practice trial on a two-item display not included in the experimental material.

After the warm-up period, the child was told that now he/she would be playing some games with the toys.

Pretest to Establish Levels of Quantitative Understanding

Children were administered a pretest in order to assess their levels of quantitative understanding as described in Chapters I and II. The pretest included a rote counting task, a cardinality task (adapted from Schaeffer et al., 1974), and a remote placement numerical reproduction task (adapted from Saxe, 1977) described in more detail below. In a pilot study all responses were videotaped and scored by two observers in order to establish inter-rater reliability. Two raters scored 15 subjects as passing each section of the pretest according to the criteria described in the following pages. The percentage of agreement between the raters was better than 95%.

Rote counting/recitation of number list. Each child was asked to count along as the examiner tapped a drum with a puppet. Only children who used number names as distinct from other words and who were able to generate at least 20 of these names, regardless of conventionality of

sequencing, were included in the study. The sequence of number names uttered was noted for up to 21 utterances. Lists were scored as conventional or unconventional.

Stating cardinal number name after counting. Each child was asked to count an array of seven fixed homogeneous linearly arranged coins placed inside a box. After the count was completed, the box lid was closed and the child was asked: "How many coins are inside the box? How many coins are there altogether?"

Counting lists and responses to the cardinal value question were recorded. Each child was scored as either giving an appropriate cardinal value or not. Appropriate cardinal responses included restating the last number name of an accurate or inaccurate count. Any other response including repeating a series of number names or stating a number name other than the last number of the previous count was considered a non-cardinal response.

Remote placement task establishing numerical correspondence between sets. Each child was presented with a pile of pennies and a display of a fixed homogeneous linear array of matching coins of set size 9 placed on the floor next to the child's seat. The fixed display was 12 x 30 cm. in size and the coins were placed 3 cm. intervals apart. The child was asked to construct an identical array on the table in front of him/her. This placement prohibited the simultaneous viewing of the two arrays and forced the child to use counting and the product of this count to obtain a correct answer. The child was asked: "Can you make a row of pennies with exactly the same number as mine? Put your pennies over here [on a mat board the same size as the model's

but placed on the table] and make just as many as I have, exactly the same number. Tell me when you're finished."

Responses were recorded in detail. Counting accuracy as determined by the number of words uttered compared to the actual set size of the model array was noted. The following scoring categories were used to distinguish quantitative behaviors on the remote placement task:

Non-quantitative Responses

Child does not attempt to establish numerical equivalence; just plays with coins; does not take any coins out to make another set; child transfers coins from floor to table without taking any new ones; child just places arbitrary number of coins on table without counting or visually comparing them to model; child just grabs a bunch of coins and places them on table; child does not count, state cardinal value, or try to match his array in spatial extent or appearance to that of model; child just "counts" coins on table without ever looking at the model.

Child makes some attempt, but is unable to establish numerical equivalence based on numerosity; child tries to move model to table or place coins on floor in order to make a perceptual comparison; does not give cardinal value of model; makes visual comparison with model based on non-numerical criteria such as spatial extent or whether coins are heads up.

Child uses trial and error method in order to establish numerical equivalence; child starts to place coins on table and then counts them and then counts model coins and does this procedure repeatedly until he/she is satisfied that equivalence is established; child counts and recounts own coins to a cardinal value to make a correspondence; child

places coins one at a time to correspond to each placement in model by going back and forth from model to own card repeatedly.

Quantitative Responses

Child uses product of his count of model to establish immediate and systematic numerical correspondence; child counts or appreciates cardinality of the numerical value of the model first and then reproduces the same number of coins; child says aloud how many coins model has before placing his own coins from pile deliberately and does not place them prior to counting them; or if child just looks at model and then places accurate number of coins on table without any overt expression of counting, he/she must respond to query about how he/she did that with an answer indicating counting or appreciation of cardinality was involved (for example, child says, "There were nine here.").

Overall scoring of quantitative levels based on pretests. Levels were determined by the number of pretests passed. If a child passed only the rote counting task, he/she was assigned to Level I. If a child passed the rote counting and cardinality tasks, but failed the numerical correspondence task, he/she was assigned to Level II. If a child passed all three tasks, he/she was assigned to Level III. The kinds of competencies required by each of the tasks implied that success on more advanced parts of the pretest required successful performance on earlier parts of the pretest. For example, success on cardinality implies an ability to distinguish number names from other words and success on numerical reproduction implies the ability to count an array to a cardinal value. Table 4 illustrates the ordering of pretest scores.

Table 4

Quantitative Level Scoring Criteria

Level	Performance Variables		
	Distinguishes Number Names from Other Words	Can Count Objects to Cardinal Value	Uses Counting and Cardinal Value in Systematic Approach to Reproduce Set
I Prequantitative	YES	NO	NO
II Semiquantitative	YES	YES	NO
III Fully Quantitative	YES	YES	YES

Experimental Tasks

There were four types of experimental tasks. These were counting with gestures, counting without gestures, labeling with gestures, and labeling without gestures. The order of presentation of non-numerical labeling and counting tasks was counterbalanced between all children. Within each task type the presentation of gesture or no-gesture condition was also counterbalanced so that each child received both counting and labeling tasks one after the other within each gesture condition. For both types of tasks (labeling and counting) set sizes were presented in a random order except that the first trial of each testing session always began with a practice two-item trial not included in the actual data. Display arrangements, linear or disorderly, were randomly alternated for each child with the entire group of set sizes presented first in one arrangement and then again in the alternate arrangement. The procedure was implemented during one testing session whenever possible. All sessions were videotaped.

Non-numerical labeling--Gesture-allowed condition. Each child was presented with 10 heterogeneous unfixed arrays of miniatures of common household objects, two each of set sizes 3, 5, 8, 12, and 20 (see Beckwith & Restle, 1966, regarding the use of particular set sizes which lend themselves to grouping strategies). One group of presentations consisted of objects in a linear arrangement and the other was in a disorderly display. The disorderly arrays were individually placed for each presentation by the experimenter who put the objects on a board in a prearranged randomly determined pattern and placed the board in front of the child. While the patterns of placement for each set size were

the same for every child, the selection of particular objects was randomly varied from one child to another. All children received objects from the same total pool of 48 objects, randomly selected for each presentation. All 48 objects were reused for each of the task conditions. The linear arrays were determined in the same manner as the disorderly arrays in that the particular sequence of objects was randomly selected and placed for each child. Objects were spaced approximately 1 cm to 2 cm apart from one another on linear arrays. See Appendix A for the particular arrangements of disorderly patterns.

During the placement of both linear and disorderly arrays the objects were screened from the child's view until all items had been positioned. Older children were just asked to close their eyes until objects were positioned. The experimenter spoke to the child about non-task related topics while making the placements in order to maintain a good rapport with the child, to prevent boredom in the child, and to deter older children from counting objects ahead of time based on auditory cues.

Each child was instructed as follows:

Big Bird has gone out shopping (again). He wants to make sure he didn't forget anything. Will you help him find out if he has everything? [Screened two-object array presented after child has agreed.] This is some of what he bought. [Screen removed or child told to open his eyes.] Tell Big Bird the names of everything here. Tell him the names of all the things you see. What do you call them? [The use of everything in addition to all comes from Elkind & Weiss, 1967.] Do the best you can so that he doesn't forget anything. [Including instructions to do the best you can comes from Fuson & Mierkiewicz, 1980, regarding the effect of effort on performance.] Tell me when you are finished.

After the practice array was completed, the first experimental array was presented with these instructions:

Here are some more things Big Bird bought [use of collection rather than class noun is based on Markman, 1978, 1979]. Tell him the names of everything here. Tell him the names of all the things you see. What do you call them? Do the best you can and tell me when you are finished.

The process was repeated until all 10 experimental arrays were labeled.

Non-numerical labeling--No-gesture condition. Ten comparable arrays using the same objects from the pool of 48 items in the gesture-allowed condition were presented one at a time. Both the disorderly and linear displays had the same spatial arrangements at each set size 3, 5, 8, 12, and 20 as in the previous condition. However, the board of objects here was placed on a platform with stationary wheels and which had two handles facing the child. Each child was instructed as follows:

Big Bird has gone out shopping (again). This is his shopping cart [pointing to platform with handles]. He wants to make sure that he didn't forget anything. Will you help him find out if he has everything? Hold onto the cart here so it doesn't roll away [examiner would not proceed until the handles were held with both hands by the child]. Now this is what he bought [screen is removed or child is asked to open his eyes]. Tell Big Bird the names of everything here. Tell him the names of all the things you see. What do you call them? Do the best you can so that he doesn't forget anything and remember to hold the cart so that it doesn't roll away. Tell me when you are finished.

After the practice array is completed, the first experimental array was presented with these instructions:

Here are some more things Big Bird bought. Tell him the names of everything here. Tell him the names of all the things you see. What do you call them? Remember to hold onto the cart and do the best you can. Tell me when you are finished.

The process was repeated until all 10 experimental arrays were labeled.

Counting--Gesture-allowed condition. The objects and array sizes and arrangements were the same ones as those used on the non-numerical labeling task.

Each child was instructed as follows:

Big Bird has gone out shopping (again). He has bought everything he needs, but now he is not sure if he has all his packages. Big Bird wants to count everything to see if he has all the things he bought. Will you help him count? [After the child agreed, the screened practice array was presented.] This is some of what he bought. [Screen was removed or child was told to open his/her eyes.] Count everything he bought. Count all these things. Count out loud. How many things are there? How many things do you see? Do the best you can so he doesn't forget anything and tell me when you are finished.

The process was continued until all 10 experimental arrays were counted.

Counting--No-gesture condition. The same materials and array arrangements were used as in the no-gesture non-numerical labeling condition.

Each child was instructed as follows:

Big Bird has gone out shopping (again). Here is his shopping cart. He has bought everything he needs, but now he is not sure he has all his packages. Big Bird wants to count everything to see if he has all the things he bought. Will you help him count? Hold onto the shopping cart so it does not roll away. [Examiner did not proceed until the handles were held with both hands by the child. After the child agreed, the screened practice array was presented.] Here is some of what he bought [screen was removed or child was told to open his eyes]. Count everything he bought. Count all these things. Count out loud. How many things are there? How many things do you see? Do the best you can and tell me when you are finished.

The process was continued until all 10 experimental arrays were counted. If at any point the child asked why the same objects were being repeated, he was told:

Big Bird wants to make extra sure that he doesn't forget anything. You know how forgetful Big Bird is.

All videotaped sessions were scored according to the following categories and codes for each array presentation.

1. Set Size
3, 5, 8, 12, 20
2. Display Configuration
0 - Linear
1 - Disorderly
3. Task Type
0 - Counting
1 - Labeling
4. Gesture Condition
0 - Gesture prohibited
1 - Gesture allowed
5. Gesture Occurrence
0 - Gestures do not occur
1 - One or more gestures do occur
6. Number of Gestures Used
0 to 98 - Actual number of gestures used on gesture-allowed condition
99 - Missing value indicating the irrelevancy of the number of gestures used on the gesture-prohibited condition
7. Number of Objects Not Pointed To
0 to 20 - Actual number of items not pointed to on gesture-allowed condition
99 - Missing value indicating irrelevancy of category on gesture-prohibited condition

8. Number of Times Objects Pointed to More Than Once
 - 0 to 98 - Actual number of times items pointed to repeatedly on gesture-allowed condition
 - 99 - Missing value indicating irrelevancy of category on gesture-prohibited condition
9. Number of Gestures Made Not Referring to Specific Objects (includes pointing in air, sweeping gestures, clumping objects together, pointing to spaces on cards)
 - 0 to 98 - Actual number of these gestures on gesture-allowed condition
 - 99 - Missing value for gesture-prohibited condition
10. Number of Names Uttered
 - 0 to 98 - Actual number of names said
11. Conventionalility of Number Names Used
 - 0 - Refers to labeling condition where conventionality was irrelevant
 - 1 - Number names said in conventional order on counting condition
 - 2 - Number names said in unconventional order on counting condition
12. Number of Objects Not Named (Skipped)
 - 0 to 20 - Actual number of objects omitted in labeling condition
 - 99 - Missing value indicating irrelevance of category under counting condition

13. Number of Times Objects Named More Than Once (Repeated)
- 0 to 98 - Actual number of names repeated in labeling condition
 - 99 - Missing value indicating irrelevance of category under counting condition
14. Time Taken to Complete an Array
- 0 to 98 - Actual number of seconds taken to complete a count
 - 99 - Missing value indicating irrelevance of category under labeling condition
15. Gestural Pattern Used-Direction of Pointing
- 0 - Category does not apply as in case of gesture-prohibited condition or when gestures are not utilized in gesture-allowed condition
 - 1 - Random direction on disorderly arrays
 - 2 - Proximal direction (proceeding from one adjacent object to another with no discernable pattern) on disorderly arrays
 - 3 - Peripheral direction (pointing to outside objects before inside ones) on disorderly arrays
 - 4 - Linear direction (pointing in rows or columns) on disorderly arrays or (pointing in one direction without skipping any objects) on linear arrays
 - 5 - Tracking without gestures (accounting for all objects while pointing to 1/3 or fewer of them) on linear or disorderly arrays

- 6 - Partial linear direction (proceeding in a straight line, but not pointing to all objects in that line) on linear arrays
- 7 - Non-linear direction (reversing direction more than twice) on linear arrays

(See Appendix B for specific gestural patterns and nuances at each set size.)

16. Gestural Techniques Used--Predominant Technique Within Each Trial

- 0 - Does not point or nod at all--gestures not used because gesture-prohibited condition or because gestures are not used on gesture-allowed condition
- 1 - Nods, but does not point--for either gesture-allowed or gesture-prohibited condition
- 2 - Global, nonspecific pointing--includes sweeping gestures, touching groups or clumps of objects, pointing in air or to spaces on card--gesture-allowed condition only
- 3 - Vague pointing in general direction of individual objects--gesture-allowed condition only
- 4 - Specific points to or touches objects one at a time--gesture-allowed condition only
- 5 - Lifts objects and replaces them randomly--gesture-allowed condition only
- 6 - Lifts objects and replaces them where they were--gesture-allowed condition only

- 7 - Lifts objects and sets them aside in orderly way--
gesture-allowed condition only
- 8 - Rearranges objects into groups or rows prior to
counting or labeling--gesture-allowed condition
only
- 9 - Uses combination of number 2 and 4, 5, 6, and/or 7.

CHAPTER IV

Results

Order of Presentation

1. Treatment of the variables under consideration
 - A. Clarification of how variables were grouped for analysis
 - B. Obtaining scores for variables for purposes of analysis
 - C. Methods of statistical analysis
2. Order of analyses by variable categories
 - A. Inter-rater reliability
 - B. Grouping of subjects
 - C. Frequency of occurrence of gesturing
 - D. Correspondence of names to gestures vs. gestures to objects
 - 1) Counting tasks
 - 2) Labeling tasks
 - E. Accuracy
 - 1) Task type differences
 - 2) Counting tasks
 - a) Overall age differences
 - b) Effects of set size
 - c) Effects of array configuration
 - d) Effects of gesture condition
 - 3) Labeling tasks
 - a) Overall age differences
 - b) Effects of set size
 - c) Effects of array configuration

- F. Time to complete counting trials
 - G. Gesture patterns
 - 1) Counting tasks
 - 2) Labeling tasks
 - H. Gestural techniques on labeling tasks
3. Summary of results

Treatment of Variables

Grouping for Analysis

The basic design of this study was a repeated measures procedure in which all subjects were presented with four sets of trials consisting of counting no-gesture, counting gesture, labeling no-gesture, and labeling gesture conditions. Within each condition, subjects were presented with 10 arrays consisting of two presentations of five set sizes arranged in both linear and disorderly configurations. Parametric data were analyzed by repeated measures ANOVA's in which subjects were grouped by age and in which set size, gesture condition, and array configuration were the repeated measures. The independent variable of task type was analyzed separately for counting and labeling conditions. Interaction effects were examined with a Tukey post hoc analysis for pairwise comparisons and/or the Scheffe post hoc analysis for grouped levels of independent variables. Non-parametric data were examined for differences by means of multiple chi square analyses or with a log-linear technique for cases in which variable interaction was hypothesized.

Scoring for Analysis

The dependent variables being studied were scored as follows:

1. Gesture occurrence. Counting and labeling trials on both gesture and no-gesture conditions were scored separately for whether or not gesturing occurred at least once during a particular item. Children were then categorized as high frequency or low frequency pointers. Subjects who pointed on more than 1/3 of the trials in the no-gesture condition were considered high frequency pointers. Subjects who pointed on less than 1/3 of the trials in the gesture-allowed condition were considered low frequency pointers. The selection of these cutoff points was based on the assumption that responding contrary to task expectations regarding the use of gestures on more than 1/3 of the trials constituted a consistent orientation rather than a chance occurrence of the use of pointing gestures.

The absolute value of cutoff points were as follows:

<u>Pointing Frequency</u>	<u>No-gesture condition (counting or labeling)</u>	<u>Gesture condition (counting or labeling)</u>
High	4 or more occurrences	7 or more occurrences
Low	3 or fewer	6 or fewer

2. Relative correspondence. The relative correspondence of the number of names uttered and the number of gestures used (word-to-gesture correspondence) was compared to the number of objects in an array and the number of gestures used (gesture-to-object correspondence). The difference between the number of words and gestures was obtained for each trial as was the difference between the number of gestures used and the actual number of objects in an array. Only absolute differences

were used since the direction of these differences was not being studied. The differences between the differences were then obtained and means of these scores were calculated for each age group. Table 5 contains a sample calculation of a relative correspondence score.

3. Accuracy. Several types of accuracy scores based on the relationship between the number of names used and the number of items in an array were obtained.

Difference accuracy scores were expressed as the absolute difference between the number of names uttered and the actual number of objects in an array. A score of zero represented an accurate count or labeling and the greater the deviation from zero, the less accurate the performance.

Proportional accuracy scores were expressed as the absolute difference between the number of names uttered and the actual number of objects in an array divided by the number of objects in that array (name-objects/objects). These scores were obtained in order to provide a measure of accuracy that took into account the relative importance of the same error at different set sizes. In effect this score provided an error per object score so that a score of .33, for example, indicated one error every three objects regardless of set size. As in the difference accuracy scores, the greater the deviation from zero, the less accurate the score. An example of a computation for an individual proportional accuracy score appears in Table 6. Mean accuracy scores were then obtained for this measure.

Absolute accuracy scores were also obtained and defined as:

Table 5

Calculation of Relative Correspondences

Number Names (a)	Number Gestures (b)	Number Objects (c)	Difference Names-Gestures (a-b)	Difference Gesture-Objects (b-c)	Relative Correspondence Score (b-c)-(a-b)
7	5	8	7-5=2	5-8=3	3-2=1

Table 6

Calculation of Proportional Accuracy Scores

Number Names	Number Objects	Difference	Accuracy
7	8	$7 - 8 = -1$	$1/8 = .125$
4	3	$4 - 3 = 1$	$1/3 = .333$

(0) = accurate--number of names uttered equals number of objects in an array

(1) = inaccurate--number of names uttered does not equal number of objects in an array

The sum of absolutely accurate trials executed were obtained for each subject within the four task conditions, i.e., count no-gesture, count gesture, label no-gesture, label gesture. Within each of these task conditions, each subject could receive a minimum score of zero and a maximum score of 10. Unlike the proportional and difference accuracy scores, which used error scores, for absolute accuracy the higher the score value, the greater the accuracy level. Means of the number of absolutely accurate trials within task conditions were derived for each age group.

4. Time. The time taken to complete each count (not labeling) was obtained in seconds and then transformed to speed of count by taking its reciprocal and multiplying it by 100. Means were also obtained for these scores.

5. Gestural pattern. Gestural pattern refers to the order or direction in which objects were pointed to in the gesture-allowed condition. Although eight gestural patterns were scored, they were reduced to four basic categories for purposes of analysis as follows:

(0) = less than 1/3 of the objects were pointed to (includes scoring categories 0, 5)

(1) = random pointing in which predominantly non-adjacent items were pointed to sequentially (includes scoring categories 1, 7)

- (2) = orderly non-linear pointing which included pointing to objects next to one another, but not in a row or column order or tracing the periphery of an array or pointing in a linear direction while skipping items along the way (includes scoring categories 2, 3, 6)
- (3) = linear pointing which indicated pointing in an orderly fashion from left to right or top to bottom without reversing direction or skipping objects, although repeating objects was permitted (includes scoring category 4 for both linear and disorderly arrays)

The predominant mode of gestural pattern was then determined for each subject over the 10 gesture-allowed items on the counting and labeling conditions. In case of a tie between patterns, the lower level pattern was selected as modal. The developmental ordering of gestural patterns was: (1) random, (2) orderly-non-linear, (3) linear, (4) no gestures used.

6. Random pointing. Within the gestural pattern categories, random pointing was selected for separate analysis. Sums of the number of random points executed by each subject were obtained within the four gesture-allowed task conditions, i.e., linear count, disorderly count, linear label, and disorderly label. The possible range of scores varied from 0 to 5. Means of these totals were obtained for each age group.

7. Gestural technique. Gestural techniques refer to the style of pointing utilized and defined in Chapter II. Each subject was scored according to the frequency with which he/she used any scoring category within 10 trials of the counting gesture and 10 trials of the labeling gesture conditions. Each subject was then categorized by the particular gestural technique he/she most often used within both counting and

labeling conditions. In case of a tie between more than one technique, the subject was categorized as using the more advanced technique. For example, if a subject pointed specifically five times and used sweeping gestures five times, the technique was scored as "pointing specifically."

Analysis of Data

Inter-rater Reliability

Inter-rater reliability on data involving the recording of gestures and names was obtained by two independent observers for five subjects seen at each age level. Based on independent viewing of videotapes, the observers were in almost complete agreement regarding the number of names and gestures observed on both labeling and counting conditions, Pearson correlation $r = .99$, $p < .01$. In addition, scoring of gestural patterns attained a rater percentage of agreement of 96 and scoring on gestural technique attained a rater percentage of agreement of 89. On the gestural technique ratings, the major source of disagreement (6%) involved opinions as to whether an object had been lifted slightly or simply touched. This disagreement, moreover, involved mostly children at the youngest age group where poor coordination may have been most easily confused with intention.

Grouping of Subjects

An initial comparison of subjects' ages and quantitative levels as determined by pretesting indicated that there was a close correspondence between age and level of quantitative understanding, Spearman's $R = .92$, $p < .001$. The percentage of agreement between age and quantitative level was also computed and as indicated in Table 7 ranged from 85 to 95. Because there was a high degree of agreement between age and quantitative

Table 7

Percentage of Agreement Based on Crosstabulation of Pretested
Quantitative Level and Age Groups

	Quantitative Level		
	Level I	Level II	Level III
Age (Years)			
3	95	5	0
4	15	85	0
7	0	10	90

Note. Percentage based on 20 subjects in each age group.

level and because developmental differences are generally expressed in terms of age groupings, it was decided that data would be analyzed by age groups rather than by groupings of subjects' levels of quantitative understanding. Quantitative level, nevertheless, will be included as an explanatory construct when the results of this study are discussed.

Frequency of Occurrence of Gesturing

In order to test for the effect of age on the frequency of occurrence of pointing gestures, sums of the number of trials on which pointing occurred were obtained for each subject within gesture conditions for both the counting and labeling tasks. Based on these totals, subjects were then divided into high and low frequency pointers (as specified on p. 69) and multiple chi square analyses were carried out between pairs of age groups within the counting no-gesture, counting gesture, labeling no-gesture, and labeling gesture conditions. As the data in Tables 8 and 9 indicate, 3- and 4-year-old children did not differ from one another on the gesture-allowed counting and labeling conditions. Both groups exhibited a high frequency of gesturing and pointed more frequently than 7-year-old children, χ^2 age 3 vs. 7 count = 4.90, $p < .05$, χ^2 age 4 vs. 7 count = 15.36, $p < .01$, χ^2 age 3 vs. 7 label = 10.03, $p < .01$, χ^2 age 4 vs. 7 label = 8.10, $p < .01$.

On the no-gesture condition, however, some difference was observed. On the no-gesture counting condition, although 3- and 4-year-old children still did not differ significantly from one another, they differed in their relationship to 7-year-old children. Only 3-year-old and not 4-year-old children gestured more frequently than 7-year-old children, $\chi^2 = 8.03$, $p < .01$. The frequency of gesture occurrence of 4-year-old

Table 8

Total Number of Subjects for Whom High Frequency Gesturing Occurred Within Each Age Group Under Each Task Condition

Age	Task Type and Gesture Condition					
	Counting			Labeling		
	3 years	4 years	7 years	3 years	4 years	7 years
No-gesture	10	5	1	14	6	1
Gesture	14	19	6	16	15	5

Note. Number of subjects within each age group = 20.

Table 9
Comparison of High and Low Frequency Gesturing by Age
(Chi Square Analyses)

Age (Years)	Task Type and Gesture Condition			
	Counting		Labeling	
	No-gesture	Gesture	No-gesture	Gesture
3 vs. 4	1.71	2.77	5.80*	.14
3 vs. 7	8.03**	4.90*	16.63**	10.03**
4 vs. 7	1.76	15.36**	2.77	8.10**

* $p < .05$.

** $p < .01$.

children was approximately midway between that of 3- and 7-year-old children. A slightly different pattern was observed in the no-gesture labeling condition. Here 3-year-old children gestured significantly more often than both 4-, $\chi^2 = 5.80$, $p < .05$, and 7-year-old children, $\chi^2 = 16.63$, $p < .01$, but 4-year-old children still did not differ from 7-year-old children.

An additional set of chi square analyses was carried out in order to compare subjects' high and low gestural occurrence levels between gesture conditions within each age group. Table 10 contains the cross-tabulations of the frequency of subjects within each age group who were categorized as high and low pointers. Each crosstabulation compares the subjects by gesture condition within specific task types, i.e., counting and labeling. As Table 11 illustrates, chi square analyses indicated that the difference between the frequency of high and low pointing by gesture condition was significant only for 4-year-old subjects on both counting and labeling tasks, χ^2 count = 10.21, $p < .01$, χ^2 label = 4.06, $p < .05$. Only the 4-year-old children showed a significant increase in pointing frequency when gesturing was allowed. Three-year-old children tended to be frequent pointers on both gesture and no-gesture conditions, while 7-year-old children tended to be infrequent pointers on both conditions.

Names-to-gestures vs. Gestures-to-objects
Correspondences

Table 12 contains the mean differences between name and gesture correspondences vs. gesture and object correspondences for each age group within counting and labeling conditions. It should be noted that

Table 10

Number of Subjects Categorized as High and Low FrequencyPointers by Age

	Task Type			
	Count		Label	
	Low	High	Low	High
Age				
3-year-olds				
No-gesture	10	10	6	14
Gesture	6	14	4	16
4-year-olds				
No-gesture	15	5	14	6
Gesture	1	19	5	15
7-year-olds				
No-gesture	19	1	19	1
Gesture	14	6	15	5

Note. Number of subjects at each age = 20.

Table 11
Comparisons of High and Low Frequency Gesturing Within
Age Groups Between Gesture Conditions

Age (Years)	Task Type	
	Count Gesture vs. No-gesture	Label Gesture vs. No-gesture
3	.833	.270
4	10.210**	4.060*
7	2.16	1.57

* $p < .05$.

** $p < .01$.

Table 12

Mean Differences Between the Correspondences of Gestures-to-Objects vs. Names-to-Gestures for Counting and Labeling Conditions

Difference	Task Type and Age (in Years)					
	Count			Label		
	3	4	7	3	4	7
Gesture-Object	4.8000	1.445	4.945	3.735	3.020	6.440
Name-Gesture	3.055	1.145	4.920	2.850	3.015	6.400
(G-O) - (N-G) difference of differences	1.745**	.300	.025	.885**	.005	.040

**p < .01.

the high gesture-object and name-gesture difference scores of the 7-year-old group were a function of that group's infrequent use of gesture. Because they used few gestures, their counts and labelings consistently reflected a greater number of both objects and names uttered compared to gestures used. Because both types of correspondence scores were high, the difference between them was small.

A three (age groups) x five (set sizes 3, 5, 8, 12, 20) x two (linear vs. disorderly configuration) repeated measures ANOVA revealed significant main effects for age and set size, but not for configuration on the correspondence variable for both counting, $F_{age} (1,57) = 18.64$, $p < .01$ and $F_{set} (4,228) = 20.06$, $p < .01$, and labeling, $F_{age} (1,57) = 17.36$, $p < .01$ and $F_{set} (4,228) = 9.46$, $p < .01$, tasks. Significant interaction effects were also found for age x set size on both counting, $F (4,228) = 12.63$, $p < .01$ and labeling, $F (4,228) = 10.00$, $p < .01$, conditions.

A post hoc analysis revealed that the youngest age group, 3-year-olds, had a significantly higher mean difference score, Tukey test, $p < .01$, than 4- or 7-year-olds on both counting and labeling conditions. The relative magnitude of the difference means indicates that the 3-year-old children's names and gestures corresponded more closely than the number of their gestures and the actual number of objects in an array. Four- and 7-year-old children, however, matched their gestures about equally well to the number of names said and the number of objects in an array. In other words, 4- and 7-year-old children who were more accurate counters and labelers (see Accuracy section) evidenced as close a correspondence between gestures and objects as between names and gestures, whereas

3-year-old children who were less accurate manifested a closer correspondence between gestures and names rather than gestures and objects.

Further post hoc analyses of these findings differed for labeling and counting conditions and so will be discussed separately below.

Post hoc analyses and set size in the counting condition. Tukey post hoc analysis indicated that there were no pairwise differences between set size relative correspondence means. A Scheffe test for grouped means, however, revealed that the greatest difference between correspondences occurred for set sizes 12 and 20 combined as compared to set sizes 3, 5, and 8 combined, Scheffe test, $p < .01$. Table 13 contains the mean differences of the correspondence of gesture and counting word vs. gesture and object at each set size collapsed over age. It was observed that at set size 3, the difference was actually in the direction of greater correspondence of gesture to object rather than of counting words to gestures. Additional post hoc analyses of the significant interaction effect of age and set size revealed that the difference in set sizes was attributable only to 3-year-olds, Scheffe test, $p < .01$. This finding made clearer in Table 13 suggests that even for the youngest counters, gestures are closely tied to the number of objects at small set sizes.

Relative correspondences and set size in the labeling condition. Similar to the counting condition results, a post hoc analysis of the difference between name and gesture vs. gesture and object correspondences by set size for the labeling condition indicated that the significant difference in set size was due to the effect of the largest set size. That is, the difference between combined set sizes 3, 5, 8, and 12 as

Table 13

Mean Differences by Set Size for Counting Word-Gesture
Correspondence vs. Gesture-Object Correspondence in
the Counting Condition by Age

Age (Years)	Set Size				
	3	5	8	12	20
3	-.93	.65	.43	2.03	6.55
4	.03	0.00	.25	.10	.25
7	0.00	0.00	0.00	.025	.10
Combined	-.30	.217	.225	.717	2.592

compared to set size 20 was significant, Scheffe test, $p < .01$, as shown in Table 14. When set size means of differences were broken down by age, the significant difference was again due to the difference in means of 3-year-olds and not those of 4- or 7-year-olds, Scheffe test, $p < .01$. It should be noted, however, that these differences were less pronounced than in the counting condition and that no unusual trends appeared for set size 3 for 3-year-olds.

Accuracy

The data were analyzed by three measures of accuracy.

Proportional accuracy--Task type differences. Table 15 contains a crosstabulation of children's proportional accuracy scores as a function of tasktype condition (i.e., counting vs. labeling). A two (count vs. label) x three (age groups) x five (set sizes) x two (configuration) x two (gesture vs. no gesture) repeated measures ANOVA utilizing proportional accuracy scores was performed. The repeated measures were set size, configuration, and gesture condition. A significant main effect for task type was found, indicating that children were significantly more accurate on labeling than counting conditions, $F(1, 114) = 31.18$, $p < .01$.

In addition, significant interaction effects for task type by age, $F(2, 114) = 32.75$, $p < .01$, and task type by gesture, $F(1, 114) = 11.28$, $p < .01$, were found.

Post hoc analyses for particular differences shown in Table 15 indicated that task type had an effect only for 3-year-olds, and not for 4- or 7-year olds, Tukey test, $p < .01$ for 3-year olds. In addition, there was a significant difference between counting and labeling accuracy for 3-year-olds only on the no-gesture condition, Tukey test, $p < .01$,

Table 14

Mean Differences by Set Size for Word-Gesture Correspondences
vs. Gesture-Object Correspondences in Labeling Condition
by Age

Age (Years)	Set Size				
	3	5	8	12	20
3	.05	.22	.27	.30	3.57
4	.02	.07	.05	.02	-.15
7	0.00	0.00	0.00	.05	.15
Combined	.02	.10	.10	.14	1.17

Table 15

Comparison of Proportional Accuracy Score Means for Counting vs.
Labeling Conditions by Age

Age (Years)	Tasktype		Difference
	Count	Label	
3	.454	.113	.341**
4	.089	.038	.051
7	.004	.003	.001
Overall	.182	.051	.131**

Note. Higher scores indicate greater error; zero indicates perfect accuracy.

** $p < .01$.

and not between counting and labeling on the gesture-allowed condition. Table 16 illustrates these within gesture condition differences. Because of these results, further discussion of accuracy score differences will be separated for counting and labeling conditions below.

Proportional Accuracy on Counting Tasks

Four variables were examined in relation to proportional accuracy on counting tasks.

Overall age differences. A three (age groups) x five (set sizes) x two (configuration) x two (gesture vs. no gesture) repeated measures ANOVA was performed on proportional accuracy scores (number names-number objects/number objects) within the counting condition. The repeated measures were set size, configuration, and gesture condition. Significant main effects for age, $F(2, 57) = 38.59, p < .01$, set size, $F(4, 228) = 4.11, p < .01$, configuration, $F(1, 57) = 4.27, p < .05$, and gesture condition, $F(1, 57) = 13.17, p < .01$, were obtained. In addition, significant interaction effects were found for age by set size, $F(8, 228) = 4.37, p < .01$, and for age by gesture condition, $F(2, 57) = 3.42, p < .05$.

As illustrated in Figure 7, post hoc analyses revealed that the main effect for age on accuracy scores was due to the significantly higher error scores of the 3-year-olds compared to 4- or 7-year olds, Tukey test, $p < .01$.

Effects of set size on proportional counting accuracy. Table 17 contains children's proportional accuracy scores as a function of age group and set size. Within age groups, differences in accuracy scores due to set size were significant only for 3-year-olds where performance

Table 16

Comparison of Mean Proportional Accuracy Scores on Labeling and Counting Conditions by Gesture Condition and Age

Age (Years)	Gesture Condition	Tasktype		
		Count	Label	Difference
3	No gesture	.525	.115	.410*
3	Gesture	.384	.111	.273
4	No gesture	.139	.138	.101
4	Gesture	.038	.037	.001
7	No gesture	.005	.004	.001
7	Gesture	.003	.003	.000

Note. Higher scores indicate greater error; zero indicates perfect accuracy.

* $p < .01$.

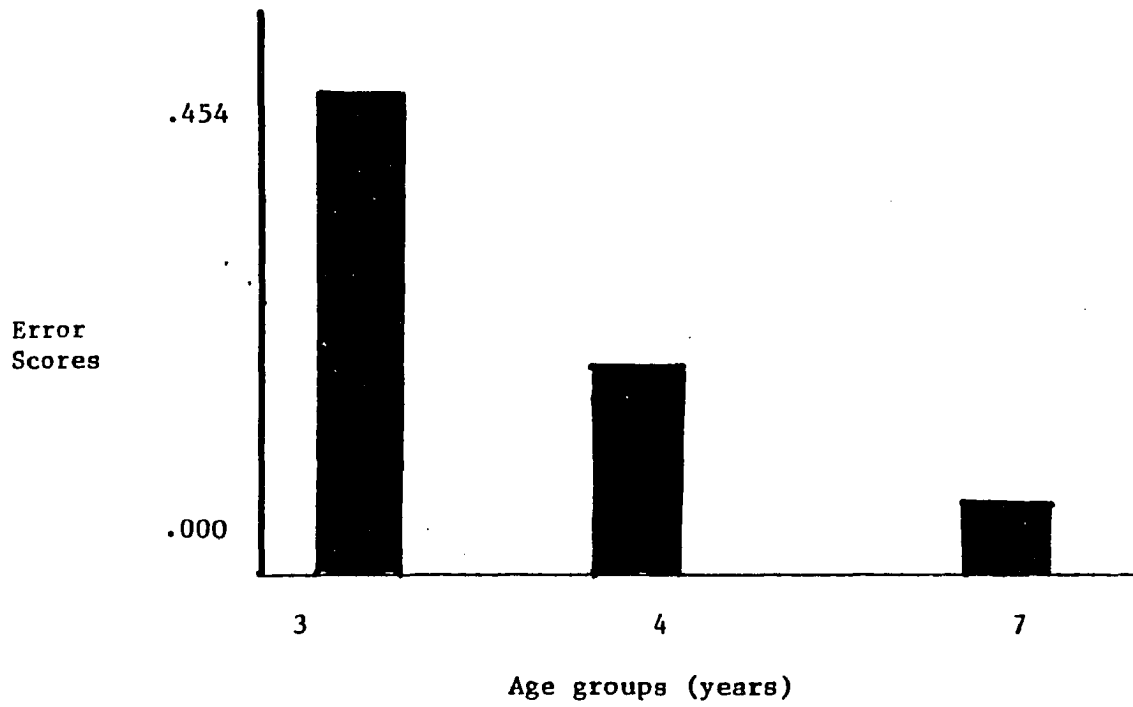


Figure 7. Proportional counting error scores by age.

Table 17

Proportional Counting Accuracy Scores by Set Size and Age

Age (Years)	Set Size				
	3	5	8	12	20
3	.759	.458	.300	.304	.451
4	.080	.045	.083	.091	.145
7	0	0	.002	.005	.013

Note. Higher scores indicate greater error; zero indicates perfect accuracy.

on set size 3 was poorer than on all other set sizes examined both in pairs, Tukey test, $p < .01$, or compared to all other set sizes combined, Scheffe test, $p < .01$. The expression of accuracy scores in terms of the proportion of error, however, probably made deviations from perfect scores more evident for smaller set sizes. This resulted in errors on set size 3 appearing greater than on all other set sizes for 3-year-olds.

Table 18 contains the mean number of counting words uttered by each age group at the various set sizes. This table indicates that although all children increased the number of words uttered as set size increased, the 3-year-old children as a group used a relatively narrow range of number words, somewhere between an average of 5 and 11 in their counts. This suggests that 3-year-old children tended to offer a similar number word list with only slight variations regardless of set size, i.e., imprecise counting in general. Moreover, as Table 19 indicates, these lists tended to consist of a relatively high proportion of subjects using unconventional counting lists as compared to the more conventional lists of 4- and 7-year-olds.

Effect of array configuration on proportional counting accuracy.

Array configuration affected the accuracy of all age groups in that children produced more counting errors on disorderly arrays than linear arrays regardless of set size or gesture condition. The mean linear proportional accuracy score was .165 while the mean disorderly score was .199, $F(1, 57) = 4.27$, $p < .05$.

Effect of gesture condition on proportional accuracy scores on counting tasks. Table 20 contains the mean proportional counting accuracy scores for age groups under the gesture and no-gesture conditions.

Table 18

Mean Number of Counting Words Uttered in Counting Condition by Age

Age (Years)	Set Size				
	3	5	8	12	20
3	5.68	7.43	8.45	9.28	10.55
4	3.45	5.40	8.78	12.48	17.00
7	3.00	5.00	8.03	11.90	19.90

Table 19

Number of Subjects Using Conventional and Unconventional Counting Lists

Age (Years)	Type of List			
	Conventional Only	Unconventional		
		1-4 Trials	5-10 Trials	11 or More Trials
3	1	8	5	6
4	10	4	5	1
7	20	0	0	0

Note. Number of subjects in each age group = 20.

Table 20

Proportional Counting Accuracy Scores by Gesture Condition and Age

	N	Gesture	No-Gesture	Difference
All ages	60	.141	.223	.082**
3-year-olds	20	.384	.525	.141**
4-year-olds	20	.038	.139	.101*
7-year-olds	20	.003	.005	.002

*p < .10.

**p < .01.

The significant main effect of gesture condition on proportional accuracy scores indicated that counting without gestures was less accurate overall than counting with gestures, $F(1, 57) = 13.17, p < .01$. However, post hoc analysis revealed that within age groups, only 3-year-old children were significantly more accurate when using gestures than when not using gestures, Tukey test, $p < .01$, although 4-year-old children showed a tendency in the same direction and approached significance at approximately the .10 level. In addition, the post hoc analysis of pairwise differences comparing relationships between age groups as contained in Table 21 indicated that while 3-year-old children were consistently less accurate than 4- to 7-year-olds on gesture allowed as well as gesture inhibited conditions, 4-year-olds were less accurate than 7-year-olds only on the no-gesture condition, Tukey test, $p < .01$. That is, 4- and 7-year-olds were equally accurate counters when allowed to gesture, but 4-year-olds could not maintain that level of high accuracy when gesturing was not permitted.

Proportional Accuracy on Labeling Tasks

Four variables were examined in relation to proportional accuracy on the labeling condition.

Overall age differences. A three (age groups) x five (set sizes) x two (linear vs. disorderly configurations) x two (gesture vs. no gesture) repeated measures ANOVA was performed on proportional accuracy scores (number names-number objects/number objects) within the labeling condition. The repeated measures were set size, configuration, and gesture condition. As in the counting condition, significant main effects were found for age, $F(2, 57) = 19.01, p < .01$, set size, $F(4, 228) = 16.89, p < .01$, and configuration, $F(1, 57) = 9.37, p < .01$.

Table 21

Means of Proportional Counting Accuracy Scores and Gesture Condition by Age

	Age			Significance		
	3 years	4 years	7 years	3 vs. 4	3 vs. 7	4 vs. 7
Gesture	.384	.038	.003	.346*	.381*	.035
No-gesture	.525	.139	.005	.386*	.520*	.134*

Note. Higher scores indicate greater error; zero indicates perfect accuracy.

*Critical difference value $Tukey_{99} = .131$.

However, unlike the counting condition, no main effect was found for gesture condition. There was, however, still an interaction effect for age by set size, $F(8, 228) = 5.50, p < .01$.

As illustrated in Figure 8, post hoc analyses revealed again that the main effect differences in accuracy for age groups were due to the lower accuracy scores of 3-year-olds compared to 4- or 7-year-olds, Tukey test, $p < .01$.

Effects of set size on proportional labeling accuracy. The breakdown in effects of set size on proportional accuracy followed a more predictable pattern in the labeling condition than it did in the counting one. Table 22 contains the mean proportional accuracy scores for each age group as a function of set size for the labeling condition. A general decrease in accuracy scores as set size increased was observed. Post hoc analyses revealed that accuracy on set sizes 3, 5, and 8 combined was significantly higher than on set sizes 12 and 20 combined, Scheffe test, $p < .01$. Even though most of this difference came from 3-year-olds compared to 4- and 7-year-olds combined, Scheffe test, $p < .01$, at least one pairwise difference between set sizes was significant for 4-year-olds, Tukey test, $p < .01$, for a comparison of set size 3 vs. 20. Seven-year-olds, however, were consistently accurate across all set sizes. Table 23 contains the mean number of label names uttered at each set size by each age group. As can be seen, the range of these means is wider than those observed on the counting condition for 3-year-olds.

Effect of array configuration on labeling proportional accuracy. As in the counting condition, disorderly arrays were performed less accurately

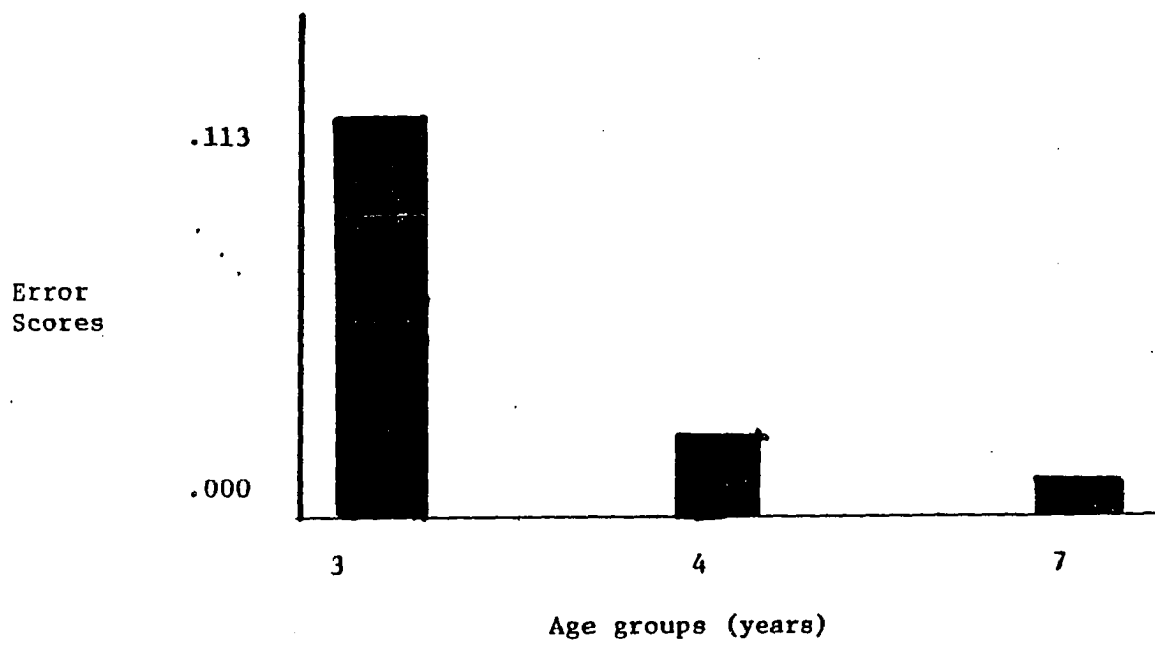


Figure 8. Proportional labeling error scores by age.

Table 22

Children's Proportional Accuracy Scores on the Labeling Condition
as a Function of Set Size and Age

Age (Years)	Set Size				
	3	5	8	12	20
3	.038	.068	.119	.101	.240
4	.004	.020	.031	.048	.092
7	0.000	0.000	.002	.008	.009

Note. Higher scores indicate greater error; zero indicates perfect accuracy.

Table 23

Mean Number of Labeling Words Uttered on Labeling Condition by
Age and Set Size

Age (Years)	Set Size				
	3	5	8	12	20
3	3.13	5.26	8.15	11.63	17.68
4	3.01	5.03	7.98	11.81	20.51
7	3.00	5.00	7.99	11.93	19.75

than linear ones across all ages, set sizes, and gesture conditions, $F(1, 57) = 9.37, p < .01$, with a mean of .064 for disorderly arrays as compared to a mean of .038 for linear arrays.

Difference Accuracy

Difference accuracy (i.e., number names-number objects) scores were analyzed separately for counting and labeling conditions.

Difference accuracy scores on counting tasks. A three (age groups) x five (set sizes) x two (configuration) x two (gesture vs. no-gesture) repeated measures ANOVA was performed on difference accuracy scores within the counting condition. The repeated measures were set size, configuration, and gesture condition. Significant main effects for age, $F(2, 57) = 77.25, p < .01$, set size, $F(4, 228) = 55.79, p < .01$, and gesture condition, $F(1, 57) = 24.32, p < .01$, were obtained. The effect for configuration approached significance, $F(1, 57) = 3.98, p < .0509$. In addition, significant interaction effects were found for age by set size, $F(8, 228) = 20.10, p < .01$, and age by gesture condition, $F(2, 57) = 5.99, p < .01$. As indicated in Figure 9, post hoc analysis revealed that 3-year-olds had significantly higher error (i.e., difference) scores than either 4- or 7-year-olds and that 4-year-olds had significantly higher error scores than 7-year-olds, Tukey test, $p < .01$.

Effects of set size on difference accuracy on counting tasks.

Table 24 contains children's difference accuracy scores as a function of set size for all age groups individually and combined. Post hoc analysis revealed that with age groups combined, more errors were made at set size 20 than at any of the other set sizes, Tukey test, $p < .01$,



Figure 9. Mean difference error scores by age.

Table 24

Mean Difference Accuracy Scores by Set Size and Age
on Counting Condition

Age (Years)	Set Size				
	3	5	8	12	20
3	2.275	2.288	2.40	3.65	9.025
4	.238	.225	.738	1.088	2.900
7	0.000	0.000	.013	.063	.250
Combined	.8375	.9375	1.025	1.60	4.058

Note. Higher scores indicate greater error; zero indicates perfect accuracy.

and that performance at set size 12 was significantly less accurate than at set sizes 3 and 5, Tukey test, $p < .05$. No differences were found between performance on set sizes 3 and 5 or between set sizes 8 and 12. Within age groups, differences in difference accuracy scores were significant for 3- and 4-year-olds with both groups having higher error scores on set size 20 as compared to performance on any of the other set sizes, Tukey test, $p < .01$. Seven-year-olds were consistently accurate across all set sizes.

Effect of array configuration on difference accuracy scores on counting tasks. The effect of array configuration on counting difference accuracy scores only approached significance, $F(1, 57) = 3.98$, $p < .0509$, but was in the direction of greater error on disorderly as compared to linear arrays.

Effect of gesture condition on difference accuracy scores on counting tasks. Table 25 contains the means of children's difference accuracy scores within age groups and for age groups combined under the gesture and no-gesture counting conditions. The significant effect of gesture condition on difference accuracy scores indicated that counting without gestures was less accurate overall than counting with gestures, $F(1, 57) = 24.32$, $p < .01$. Somewhat in contrast to the proportional accuracy results, post hoc analysis revealed that within age groups, both 3- and 4-year-olds were significantly more accurate when using gestures than when not using gestures, Tukey test, $p < .01$. Additional post hoc analysis of pairwise differences comparing relationships between age groups, contained in Table 26, indicated that while 3-year-olds were consistently less accurate than 4- or 7-year-olds on gesture allowed

Table 25

Mean Accuracy Difference Scores by Gesture Condition and
Age on Counting Task

Age (Years)	Gesture Condition		Difference
	Gesture	No-gesture	
3	3.38	4.48	1.10*
4	.59	1.46	.87*
7	.06	.08	.02
Combined	1.34	2.00	.66*

Note. Total number of subjects in each age group = 20. Higher scores indicate greater error; zero indicates perfect accuracy.

* $p < .01$.

Table 26

Means of Difference Accuracy Scores by Gesture Condition and Age on Counting Task

	Age			Significance		
	3 years	4 years	7 years	3 vs. 4	3 vs. 7	4 vs. 7
Gesture	3.38	.59	.06	2.79**	3.32**	.53
No-gesture	4.48	1.46	.08	3.02**	4.40**	1.38**

Note. Higher scores indicate greater error; zero indicates perfect accuracy.

*Critical difference value $Tukey_{95} = .6638$.

**Critical difference value $Tukey_{99} = .7841$.

as well as gesture inhibited conditions, 4-year-olds were less accurate than 7-year-olds only on the no-gesture condition, Tukey test, $p < .01$. That is, again as in the proportional accuracy counting results, 4- and 7-year-old counters were equally accurate when allowed to gesture, but when gesturing was not permitted, 4-year-old children could not maintain the same high level of accuracy.

Difference accuracy scores on labeling tasks. A three (age groups) x five (set sizes) x two (linear vs. disorderly configuration) x two (gesture vs. no gesture) repeated measures ANOVA was performed on difference accuracy scores (number names-number objects) within the labeling condition. The repeated measures were set size, configuration, and gesture condition. Significant main and interaction effects observed were comparable to those found on the proportional accuracy analyses for the labeling condition. That is, significant main effects were found for age, $F(2, 57) = 18.97$, $p < .01$, set size, $F(4, 228) = 35.14$, $p < .01$, and configuration, $F(1, 57) = 7.25$, $p < .01$. Again, unlike the counting condition, no main effects were found for gesture condition. There was also an age by set size interaction, $F(8, 228) = 12.22$, $p < .01$.

As indicated in Figure 10, post hoc analysis revealed again that the main effect for age groups was due to the lower accuracy scores of 3-year-olds compared to 4- or 7-year-olds, Tukey test, $p < .01$. No differences were found between 4- and 7-year-olds.

Effects of set size on difference accuracy scores for labeling tasks. Table 27 contains the difference accuracy score means for each age group as a function of set size for the labeling condition. As in the

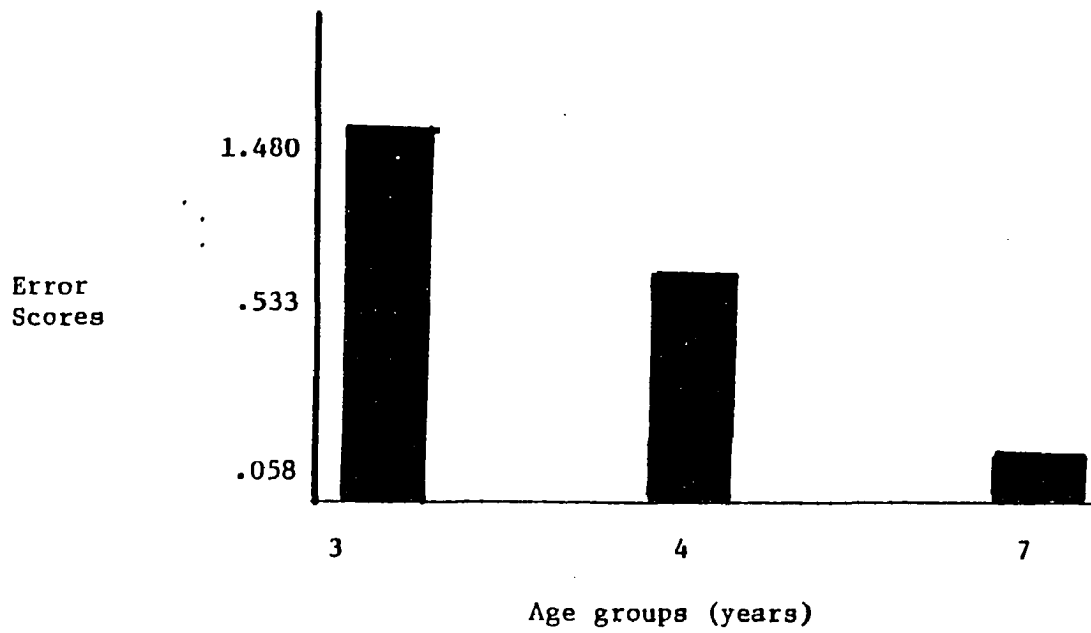


Figure 10. Difference error scores by age on labeling task.

Table 27

Mean Difference Accuracy Scores by Set Size and Age
on Labeling Condition

Age (Years)	Set Size				
	3	5	8	12	20
3	.113	.338	.950	1.210	4.800
4	.010	.100	.250	.463	1.840
7	.000	.000	.010	.100	.180
Combined	.079	.146	.404	.591	2.270

Note. Higher scores indicate greater error; zero indicates perfect accuracy.

proportional accuracy scores data, a general decrease in accuracy scores as set size increased was observed. Post hoc analysis revealed that across all ages performance on set size 20 was significantly less accurate than on all other set sizes, Tukey test, $p < .01$. Further post hoc analysis revealed that these differences in set size performance were due to differences within 3- and 4-year-old groups, both of which were significantly less accurate on set size 20 than on all other set sizes, Tukey test_{age 1}, $p < .01$ all set sizes, Tukey test_{age 2}, $p < .01$ set sizes 3, 5, 8, $p < .05$ set size 12.

Effect of array configuration on difference accuracy on labeling tasks. As in the proportional accuracy analysis, the difference accuracy ANOVA for repeated measures revealed that disorderly arrays were performed significantly less accurately than linear arrays across all ages, set sizes, and gesture conditions, $F(1, 57) = 7.25$, $p < .01$, with a mean linear score of .517 and a mean disorderly score of .865.

Absolute Accuracy

A three (age) x two (counting or labeling task) repeated measures ANOVA on absolute accuracy scores (perfect correspondence between number of names uttered and number of objects in an array) indicated that absolute accuracy differed for counting and labeling conditions, $F(1, 57) = 74.84$, $p < .01$. Mean absolute accuracy scores across ages was 6.06 for counting and 7.79 for labeling trials. A total of 20 was the maximum score possible under each task type. A significant age by task type interaction effect, however, indicated that again greater labeling accuracy occurred primarily in 3-year-olds, Tukey test, $p < .01$. On the absolute accuracy measure, though, 4-year-olds also approached

significance at the .05 level. The critical value for a significant Tukey test was 1.42 at the .05 level and the count minus label difference score on absolute accuracy was 1.40 for 4-year-olds.

Because of these observed differences and in order to be consistent with proportional and difference accuracy analyses, absolute accuracy was analyzed separately for counting and labeling tasks.

Absolute accuracy on counting tasks. Three two-way repeated measures ANOVAs were carried out in order to assess the effects of set size, configuration, and gesture condition on absolute accuracy for counting tasks.

Effects of set size on absolute accuracy on counting tasks. A three (age) x five (set size) repeated measures ANOVA with set size as the repeated measure was performed. A significant main effect was found for set size, $F(4, 228) = 43.03$, $p < .01$ and a significant interaction effect was found for age and set size, $F(8, 228) = 6.03$, $p < .01$. Post hoc analysis for age groups combined revealed that except for set sizes 3 and 5, absolute accuracy scores decreased as set size increased for pairwise comparisons of ordered set sizes, Tukey test, $p < .05$ for 5 vs. 8, 8 vs. 12, Tukey test, $p < .01$ for 12 vs. 20. Table 28 contains the mean absolute accuracy scores at each set size for all ages combined and Table 29 contains a summary of the significance of pairwise comparisons between set size scores for all ages combined. Table 30 contains the absolute accuracy means for set sizes within each age group. Further post hoc analysis of the data indicated that within age groups these pairwise differences were significant only for 4-year-old children whose absolute accuracy scores differed between set sizes 8 and 12, Tukey test,

Table 28

Mean Absolute Accuracy Scores by Set Size and Ages (Combined)
on Counting Task

Set Size				
3	5	8	12	20
3.03	2.98	2.57	2.18	1.47

Note. Totals represent the mean number of absolutely accurate counts made at each set size with range from 0 to 4.

Table 29

Pairwise Differences Between Absolute Accuracy Means by Set Size
and Combined Ages in the Counting Condition

Set Size			
3 vs. 5	5 vs. 8	8 vs. 12	12 vs. 20
.05	.41*	.39*	.71**

* $p < .05$.

** $p < .01$.

Table 30

Absolute Accuracy Score Means by Set Size and Age
in Counting Condition

Age (Years)	Set Size				
	3	5	8	12	20
3	1.35	1.30	.75	.65	.10
4	3.75	3.65	3.00	2.10	1.15
7	4.00	4.00	3.95	3.80	3.15

Note. Range of scores is 0 to 4, with 4 equal to being accurate on all trials.

$p < .05$, and between 12 and 20, Tukey test, $p < .01$. Scheffe tests of grouped means within age groups, however, showed that combined means for set sizes 8, 12, and 20 were significantly different from one another for 3-year-olds as well as 4-year-olds, Scheffe test, $p < .01$, but not significant for 7-year-olds.

Effect of array configuration on absolute accuracy scores on counting tasks. A three (age groups) x two (linear or disorderly configuration) repeated measures ANOVA was carried out with array configuration as the repeated measure. As in the proportional accuracy analysis, there was a significant main effect for configuration, $F(1, 57) = 17.59$, $p < .01$ such that more linear arrays were counted accurately than disorderly arrays. The mean linear score was 6.35 as compared to the mean disorderly score of 5.73. A significant interaction effect between age and configuration was also obtained, $F(2, 57) = 3.17$, $p < .05$.

A post hoc analysis of the age and configuration interaction revealed that only 4-year-old children were significantly more accurate on the linear than on the disorderly arrays, Tukey test, $p < .01$. Table 31 contains the mean absolute accuracy scores within age groups for linear and disorderly array configurations. As seen in the table, 3-year-old children were rarely accurate on either configuration and 7-year-old children were almost always accurate regardless of array configuration.

Effect of gesture condition on absolute accuracy scores on counting tasks. A three (age groups) x two (gesture condition) repeated measures ANOVA was performed on absolute accuracy scores with gesture condition

Table 31

Mean Absolute Counting Accuracy Scores and Array
Configuration by Age

Age (Years)	Array Configuration	
	Linear	Disorderly
3	2.35	1.80
4	7.15	6.05
7	9.55	9.35

Note. Range of scores is 0 to 10, with 10 indicating accurate on all trials.

as the repeated measure. Significant main effects were found for age, $F(2, 57) = 111.68$, $p < .01$, and gesture condition, $F(1, 57) = 35.32$, $p < .01$. There was also a significant interaction effect between gesture condition and age, $F(2, 57) = 6.95$, $p < .01$. A post hoc analysis revealed that 7-year-old children were significantly more accurate in counting than either 3- or 4-year-old children and that 4-year-old children counted significantly more accurately than 3-year-old children, Tukey test, $p < .01$. Further post hoc analysis indicated that both 3-year-old and 4-year-old children counted more accurately when gesturing was permitted than when gesturing was not allowed, Tukey test, $p < .01$. Gesture condition did not affect the absolute accuracy scores of 7-year-old children. Table 32 contains the mean absolute accuracy scores of each age group under both gesture conditions.

Absolute accuracy on labeling tasks. Three two-way repeated measures ANOVAs were carried out in order to assess the effects of set size, configuration, and gesture condition on absolute accuracy scores.

Effect of set size on absolute accuracy on labeling tasks. A three (age groups) x five (set size) repeated measures ANOVA with set size as the repeated measure was performed. A significant main effect was found for set size, $F(4, 228) = 62.77$, $p < .01$ and a significant interaction effect was found for age and set size, $F(8, 228) = 11.99$, $p < .01$. Table 33 contains the means of absolute accuracy scores for each age group singly and combined at each set size. A post hoc analysis with age groups combined revealed that set size 5 was labeled significantly more accurately than set size 8 and that set size 12 was labeled significantly more accurately than set size 20, Tukey test, $p < .01$.

Table 32

Mean Absolute Accuracy Scores Within Gesture Condition
on Counting Task by Age

Age (Years)	Gesture Condition	
	Gesture	No-gesture
3	2.70	1.45
4	7.55	5.65
7	9.60	9.40

Note. Possible range of scores is from 0 to 10.

Table 33

Mean Absolute Accuracy Scores by Set Size and Age
on Labeling Task

Age (Years)	Set Size				
	3	5	8	12	20
3	3.70	3.10	2.20	1.90	.70
4	3.95	3.80	3.50	3.10	2.00
7	4.00	4.00	3.95	3.70	3.65
Combined	3.88	3.63	3.21	2.92	2.11

Note. Range of scores is between 0 and 4.

Further post hoc analyses within age groups indicated that for 3-year-olds there was a difference in performance between set size 5 and set size 8 and between set size 12 and set size 20, Tukey test, $p < .01$. For 4-year-olds there was a difference only between set size 12 and set size 20, Tukey test, $p < .01$. Seven-year-olds again had no set size differences.

Effect of array configuration on absolute accuracy scores on labeling tasks. A three (age groups) x two (configuration) repeated measures ANOVA was carried out with array configuration as the repeated measure. There was a significant main effect for configuration, $F(1, 57) = 27.98$, $p < .01$ with a linear mean of 8.32 and a disorderly mean of 7.30. Unlike the proportional and difference accuracy results, however, absolute accuracy scores yielded a significant age by configuration interaction effect, $F(2, 57) = 4.20$, $p < .05$. The overall effect of configuration, therefore, was due primarily to the difference between linear and disorderly scores within the 4-year-old group, Tukey test, $p < .01$, although 7-year-olds did approach significance as well. Table 34 contains the mean scores for age groups on this variable and the differences between absolute accuracy configuration scores.

Effect of gesture condition on absolute accuracy scores on labeling tasks. A three (age groups) x two (gesture vs. no-gesture) repeated measures ANOVA was performed. The repeated measure was gesture condition. A significant main effect was found for age, $F(2, 57) = 38.52$, $p < .01$, but no effect was found for gesture condition. A post hoc analysis revealed that as in the counting condition, 3-year-old children were less accurate in labeling (mean = 5.68) than both 4-year-old

Table 34

Means and Differences on Absolute Accuracy Scores and
Configuration Effects by Age on Labeling Task

Age (Years)	Configuration		Difference
	Linear	Disorderly	
3	5.95	5.40	.55
4	9.00	7.20	1.80**
7	10.00	9.30	.70

*critical value Tukey_{.95} = .73

**critical value Tukey_{.99} = .87

(mean = 8.00) and 7-year-old (mean = 9.70) children, Tukey test, $p < .01$, and that 4-year-old children were significantly less accurate than 7-year-old children, Tukey test, $p < .05$.

Time to Complete Counting Trials

A three (age groups) x five (set sizes) x two (configurations) x two (gesture condition) repeated measures ANOVA was carried out for time (i.e., speed) measurements on the counting task condition. The repeated measures were set size, configuration, and gesture condition. Significant main effects were found for age, $F(2, 51) = 7.18$, $p < .01$, set size $F(4, 204) = 34.86$, $p < .01$, and configuration, $F(1, 51) = 5.28$, $p < .05$, but no main effects were found for gesture condition. There were no significant interaction effects.

Post hoc analyses indicated that the oldest group, the 7-year-olds, counted fastest, Scheffe test, $p < .01$, and that the youngest group, the 3-year-olds, as compared to the two oldest groups was slower on disorderly than linear configurations, Scheffe test, $p < .05$. In addition, time to complete a count tended to increase with set size up to set size 12, Scheffe test, of pairwise differences, $p < .01$.

Gestural Patterns

Gestural patterns were analyzed separately for counting and labeling conditions.

Gestural patterns and counting tasks. A preliminary examination of the data was made in order to categorize subjects by their gesture patterns (i.e., direction of pointing), counting accuracy, and age level. In this context, accurate counting was considered to be a perfect match between the number of counting words uttered compared to the number of

objects in an array. All other responses were considered inaccurate counts. Each subject was then designated as primarily an accurate or inaccurate counter depending upon whether the subject had more accurate or inaccurate responses on the 10 gesture-allowed items within the counting condition. In case of a tie, lower level responding was selected (i.e., inaccurate) in order to compensate for the possible ceiling effect of the oldest group. The predominant mode of gestural pattern was also determined for each subject over the 10 gesture-allowed items on the counting condition. Again in case of a tie between patterns, the lower level pattern was selected as modal. The developmental ordering of gestural patterns was: (1) random, (2) orderly-nonlinear, (3) linear, (4) no gestures used.

Table 35 contains a frequency count within age groups of subjects assigned to one of the four gestural pattern categories and one of the two accuracy categories. A log-linear analysis was performed on these data in order to examine all models describing the effect of age level on counting accuracy and gestural pattern as well as the interaction between gestural pattern and accuracy. Table 36 contains the chi square likelihood ratios and probabilities of significance of these models. As can be seen, any model that did not include age group in interaction with the other two variables showed little or no significance. Only two models, 7 and 8, were significant, χ^2 likelihood ratio₇ = 7.83, $p < .5514$, χ^2 likelihood ratio₈ = 1.72, $p < .9437$. Model 7 included the interaction of age group both with accuracy and with gestural pattern. Model 8 included these interactions and, in addition, accounted for the interaction between gestural pattern and accuracy. As Table 37

Table 35

Frequency of Subjects Assigned to Gestural Pattern and Counting Accuracy Categories on the
Gesture-Allowed Condition by Age

Age (Years)	Gestural Pattern and Accuracy							
	Random		Orderly-nonlinear		Linear		No Pointing	
	Accurate	Inaccurate	Accurate	Inaccurate	Accurate	Inaccurate	Accurate	Inaccurate
3	0	8	0	1	2	4	1	4
4	1	0	5	2	11	0	1	0
7	0	0	1	0	0	6	13	0

Note. Number of subjects within each age group = 20.

Table 36

Log-linear Analysis of Models of Interactions Among Variables of
Age (A), Gestural Pattern (G), and Counting Accuracy (S)

Models	d.f.	Likelihood Ratio Chi Square	Probability
(1) A,S,G,	17	67.78	0.0000
(2) A,GS	14	54.53	0.0000
(3) AS,G	15	34.76	0.0027
(4) S,AG	11	40.85	0.0000
(5) AS,GS	12	21.51	0.0434
(6) AG,GS	8	27.60	0.0006
(7) AS,AG	9	7.83	0.5514
(8) AS,AG,GS	6	1.72	0.9437

Table 37

Comparison of Significant Models of Log-linear Analysis Involving Interactions Among Variables of Age (A), Gestural Pattern (G), and Counting Accuracy (S)

Model	d.f.	Likelihood Ratio Chi Square
(7) AS, AG	9	7.83
(8) AS, AG, GS	6	1.72
Difference		
	3	6.11

Note. Comparison of Models 7 and 8 indicates that a Chi Square difference of 6.11 with 3 d.f. is not significant at .05 level.

shows, the additional interaction did not add any significant information beyond that accounted for by Model 7. Therefore, it can be concluded that the high probability of Model 8 was due to the inclusion of extraneous information, namely the impact of the accuracy and gestural pattern interaction. Model 7, then, was the most parsimonious significant model explaining the data and indicated that counting accuracy and gestural pattern independently of one another were each affected by age level.

Table 38 summarizes the data as percentages of patterns and accuracy calculated independently of one another and indicates more clearly the way in which predominant gestural patterns varied as a function of age. In summary, Tables 35 and 38 in conjunction with the supporting evidence of the log-linear analysis indicate that 3-year-old children were predominantly inaccurate counters (85%) who tended to be inconsistent in their use of gestural patterns although they pointed in a random direction (40%) more often than in any other. Four-year-old children tended to be largely accurate (90%) and used gestures primarily in a linear (55%) or almost linear (35%) fashion. Seven-year-old children tended not to use any gestures (65%) more often than any particular gestural pattern, but still maintained perfect counting accuracy (100%). If gestures were used in this group, they were most often linear (30%) in direction and never random (0%).

Random pointing and counting tasks. The occurrence of random gestural patterns as an indicator of the non-tracking function of gesture was examined in more detail. Table 39 contains the means of the total number of random points for 3- and 4-year-olds (the two groups for whom random patterns occurred) within four task conditions (count linear,

Table 38

Percentages of Predominant Gestural Pattern Responses and Absolute Accuracy Scores for Subjects by Age on the Counting Condition

Age (Years)	Accuracy		Gestural Pattern			
	Accurate	Inaccurate	Random	Nonlinear Orderly	Linear	No Point
3	15	85	40	5	30	20
4	90	10	5	35	55	5
7	100	0	0	5	30	65

Note. N = 20 in each group.

Table 39

Mean Frequency of Random Pointing by Task Condition for 3- and 4-year-olds

Age (Years)	Task Conditions			
	Linear Count	Disorderly Count	Linear Label	Disorderly Label
3	1.45	2.00	1.15	2.10
4	.40	.70	.60	.80

Note. Range of scores = 0 to 5.

count disorderly, label linear, label disorderly). A one-way non-repeated measures ANOVA comparing the number of random points for 3- and 4-year-olds was carried out for each task condition. No differences were found between groups on the linear label condition, but for all other conditions 3-year-old children consistently made more random points than 4-year-old children, $F_{\text{linear count}}(1, 38) = 8.10, p < .01$, $F_{\text{disorderly count}}(1, 38) = 11.03, p < .01$, and $F_{\text{disorderly label}} = 12.59, p < .01$.

Gestural patterns and labeling tasks. Subjects were categorized by gesture pattern for labeling tasks in the same way that was previously described for counting tasks. Labeling accuracy, however, was not examined in this context. Table 40 contains a crosstabulation of children grouped by age level and predominant use of gestural pattern for the labeling task. An inspection of this table reveals that 3-year-old children were predominantly random pointers, 4-year-old children were predominantly linear pointers, and 7-year-old children rarely pointed.

Gestural Techniques

Gestural techniques, or styles of pointing, were observed on the labeling condition only. A preliminary examination of the data was made in order to categorize subjects according to their predominant mode of gestural technique. The predominant mode was defined as the most frequently occurring technique for each subject on the 10 trials of the gesture-allowed labeling condition. In case of a tie between techniques, the highest level of technique was selected in order to maximize the possibility of finding numerical strategies.

Table 40

Frequency of Predominant Gestural Pattern Used on the
Labeling Condition by Age

Age (Years)	Gestural Patterns			
	Random	Orderly-Nonlinear	Linear	No Point
3	8	5	2	5
4	4	1	10	5
7	0	2	2	16

Note. N = 20 in each age group.

Table 41 contains the frequency of subjects within each age group who predominantly used each type of gestural technique. An examination of these data revealed that the frequency of occurrence of clearly numerical pointing techniques, namely grouping items prior to labeling or systematically removing already labeled objects, was extremely low for all groups. The other types of pointing techniques, while potentially useful as part of a quantitative approach to labeling, could not be clearly distinguished from gesturing used to serve a referential function. For example, a strategy such as lifting objects and replacing them could be viewed as a tracking technique or as a means of emphasizing the connection between a label and object. The failure to find clearly numerical pointing techniques in conjunction with the observed infrequency of pointing in general for 7-year-olds (see section on gesture patterns on the labeling task) indicated that further analysis of the gestural technique data was unwarranted.

Summary of Results

The results of this study are summarized below in terms of the proposed hypotheses.

Hypothesis 1 predicted that there would be a high correlation between age and level of quantitative understanding. This hypothesis was supported.

Hypothesis 2 predicted that 2- to 3-year-old children would use pointing gestures on more trials than 4- to 5-year-old children and that 4- to 5-year-old children would point on more trials than 7- to 8-year-old children. This hypothesis was largely supported. The 4-year-old children consistently pointed more often than the 7-year-old children

Table 41

Frequency of Predominant Gestural Technique by Age
on Labeling Condition

Age (Years)	Gestural Technique ^a									
	0	1	2	3	4	5	6	7 ^b	8 ^b	9
3	5	0	0	0	6	3	5	1	0	0
4	4	0	0	0	10	1	5	0	0	0
7	11	3	0	0	5	0	1	0	0	0

^aGestural Technique Code

0 = No pointing

1 = Nods

2 = Sweeping gestures

3 = Vaguely directed pointing

4 = Points specifically with finger or hand

5 = Lifts objects and replaces them randomly

6 = Lifts objects and replaces them where they were

7 = Sets objects aside as labeled**

8 = Rearranges or groups objects prior to labeling**

9 = Combines sweeping gestures with specific points

^bIndicates numerical or quantitative gestural strategies

on all gesture allowed conditions. On the gesture prohibited conditions, the 3-year-old children gestured more often than the 4-year-old children on the labeling task. On the no-gesture counting task the 4-year-old group pointed with a frequency somewhere between the 3- and 7-year-old groups, although the 4-year-old group was not significantly different from either of the other groups. The 3-year-old and 7-year-old groups, however, did significantly differ from one another. The 4-year-old group was the only one that pointed significantly more often on the gesture than the no-gesture condition, for both counting and labeling tasks. Four- and 3-year-old children pointed with equal frequency on both counting and labeling gesture allowed conditions.

Hypothesis 3 predicted that the 2- to 3-year-old children would have a closer numerical correspondence between names uttered and gestures used than between gestures used and the actual number of objects in an array. This hypothesis was supported for both counting and labeling conditions although this relationship was observed for larger set sizes only and occurred on more set sizes for counting than for labeling conditions.

Hypothesis 4 predicted that only 4- to 5-year-old children would count and label more accurately on the gesture allowed than on the gesture inhibited condition. This hypothesis received only partial support. The results of the proportional accuracy score analyses indicated that the effect of gesture on accuracy was different for counting and labeling tasks. No differences were found between accuracy on gesture and no-gesture conditions for the labeling task. On the counting task, contrary to expectations, only the 3-year-old group was

significantly more accurate on the gesture allowed than the gesture prohibited condition. As predicted, the 4-year-old children showed a strong tendency in the same direction, although this difference did not quite reach significance. Compared to the 7-year-olds, however, the 4-year-old children were significantly less accurate in counting on the gesture prohibited condition, but equally accurate on the gesture allowed condition.

The results of the difference accuracy scores analysis indicated again that gesture condition had no effect on labeling accuracy for any age group. On the counting tasks, however, this measure of accuracy resulted in both 3- and 4-year-old children achieving significantly greater accuracy on the gesture allowed than gesture prohibited conditions. More consistent with proportional accuracy score results was the finding that 4-year-old children were more accurate than 7-year-old children on the no-gesture counting condition, but equally accurate on the gesture allowed condition. The results of absolute accuracy score analysis supported the findings of the difference accuracy analyses regarding the findings of the effect of gesture condition on counting accuracy.

Hypothesis 5 predicted that within the gesture condition, accuracy would be affected by set size and array configuration only for 4- to 5-year-old children. This hypothesis received partial support. The proportional accuracy results indicated that set size affected counting and labeling tasks differently. On labeling tasks 3- and 4-year-old children were less accurate on smaller set sizes than larger ones. This difference was more pronounced for the 3-year-old rather than the 4-year-

old group. On the counting tasks only the 3-year-old children showed an effect for set size, but unexpectedly were least accurate on the smallest set size. It was observed that these children tended to utter between only 5 and 11 names per count, often in an unconventional sequence, regardless of the fact that set size ranged from 3 to 20. This narrow number range may have distorted the effect of set size using proportional accuracy scores. Further analyses using difference accuracy scores and absolute accuracy scores indicated that this was probably the case.

On the difference accuracy and absolute accuracy analyses, accuracy for 3- and 4-year-old groups declined with increasing set size on both counting and labeling tasks. Small arrays led to consistently greater accuracy. The 7-year-old group was highly accurate across all set sizes on counting and labeling tasks for all measures of accuracy.

The effects of array configuration on accuracy were also examined under the three measures of accuracy. The proportional accuracy results indicated that disorderly arrays were consistently performed less accurately than linear arrays across all ages and set sizes for both counting and labeling conditions. The difference accuracy results were consistent for the labeling condition, but though in the same direction, only approached significance on the counting condition. The absolute accuracy results in general supported the findings of the other analyses, but indicated that the effect for configuration was due only to differences within the 4-year-old group.

Hypothesis 6 predicted that 4- to 5-year-old children would take longer to complete counting tasks under the gesture than the no-gesture

condition. This hypothesis was not confirmed. Speed of counting did not vary with gesture condition for any age level.

Hypothesis 7 predicted that in the counting gesture condition, gestural function as inferred from gestural patterns would be associated with age and counting accuracy levels. This hypothesis was confirmed. More orderly directions of gestural patterns were associated with greater accuracy for 4-year-old children while more disorganized patterns and inaccuracy were associated with the 3-year-old children. The 7-year-old children tended to use overt pointing relatively infrequently although they usually were accurate in both counting and labeling tasks. When they did gesture, it tended to be in a linear direction. In addition, the 3-year-old children used random pointing patterns significantly more than either of the older age groups on both labeling as well as counting tasks on both linear and disorderly arrays.

Hypothesis 8 predicted that in the labeling gesture condition, only the 7-year-old children would use systematic or numerical pointing strategies such as reorganizing objects into sets. This hypothesis received no support. The 7-year-old children did not seem to apply such strategies to the labeling condition any more often than the younger children did, but this may at least in part have been a function of the infrequency with which they gestured overall.

CHAPTER V

Discussion

The results of this study largely support the overall hypothesis that gesture in counting activities undergoes a shift in function as children develop greater understanding of the counting process and its underlying quantitative relationships. There were, however, several unexpected findings regarding the ways in which this functional shift occurs over development. The more surprising of these were the observations that (1) very young children do indeed seem to increase their counting accuracy to some extent through the use of gesture and that (2) the exhaustive labeling of objects tends to precede rather than follow the development of counting accuracy. The following discussion is an attempt to explore the theoretical implications of the findings that both support and challenge the major hypotheses of this study in terms of the three developmental levels of quantitative understanding proposed earlier.

Hypothesis 1--Age and Level of
Quantitative Understanding

As expected, children's ages and levels of quantitative understanding were closely correlated. Children between the ages of about 2 and 3 usually had a non-quantitative understanding of the counting process and, therefore, would be expected to approach counting as if it were simply a labeling activity. Their pointing, then, would serve a referential rather than a partitioning function. Children between the ages

of about 4 and 5 usually had a semi-quantitative understanding of the counting process. Although they could begin to count objects to a cardinal value, they did not spontaneously use the concept of cardinality as a means of comparing two sets of objects. Nevertheless, it would be expected that children at this age would deploy gesture as a partitioning aid in order to account for each and every object once and only once in their effort to obtain an accurate count and cardinal value. Children between the ages of approximately 7 and 8 usually had developed a fully quantitative understanding of the counting process which reflects the ability to use the cardinal value of a count in order to compare two sets of objects and implies the capacity for adapting quantitative knowledge to non-quantitative contexts. It would be expected that although these children might use overt gesturing less frequently than either of the two younger groups, to the extent that it would occur, gesturing would be deployed as a partitioning aid for both quantitative and non-quantitative tasks.

Overall the finding that age and quantitative understanding are closely tied together supports the point of view that very young children, despite appearances, are not engaging in the same activity as older children and/or adults when they participate in a counting activity. The external indicators of the counting process, namely uttering number words and pointing, do not necessarily mean that counting has a quantitative basis and without that basis, counting is out of the realm of "mathematics" and in the realm of other non-quantitative language activities.

Hypothesis 2--Ability to Inhibit Gesture

Because the referencing function of gesture has its roots in the sensori-motor period of development, a primary index of this function is the extent to which verbalizations are tied to motor activity. This would mean that gesture would be extremely difficult to inhibit on both labeling and counting tasks for very young children, but that as the referencing function shifted toward one of partitioning, middle level children should show an increased ability to inhibit gesture on counting tasks in which the use of pointing was specifically prohibited. It would also be expected that the oldest, 7-year-old, children would have the least difficulty inhibiting gesture on counting tasks and, in addition, be able to inhibit gesture on labeling tasks as well. The latter inhibition would be based on the hypothesis that pointing on labeling tasks assumes the same quantitative non-referential function as in counting tasks at this level.

Several findings of this study support the contention that such a shift in gestural function occurs over development. This shift is reflected in the varying frequency with which overt gesturing occurred in the three age groups observed. First, the 4-year-old group pointed less frequently than the 3-year-old group and more frequently than the 7-year-old group on the no-gesture counting and labeling conditions. This suggests that the 4-year-old group is in a transitional period of movement away from the use of gesture as a referential tool and movement toward the use of gesture as a partitioning aid.

In addition, the 3-year-old group pointed with high frequencies on both the no-gesture and gesture allowed counting and labeling conditions,

the 7-year-old group pointed with low frequencies on both conditions, and the 4-year-old group pointed significantly more often on the gesture allowed than the gesture prohibited conditions. This supports the position that very young children are less able to separate their pointing gestures from their verbalizations than either of the older groups and that this reflects their use of gesture as a referencing tool. In contrast, the middle age group was able to use number words and labels without the accompaniment of overt pointing gestures. This inhibition reflects the emergence of gesture as a partitioning aid, independent of its connection to the naming activity itself. As such it implies the use of number words with some quantitative understanding as distinguished from the use of number words as in any other labeling activity. The fact that this pattern of gestural inhibition applied to the labeling as well as the counting condition suggests additionally that perhaps 4-year-old children are already applying quantitative techniques to non-quantitative contexts and in this way resemble the 7-year-old group.

In other ways, however, the 4-year-old group bore a closer resemblance to the 3-year-old group. When 4-year-old children were given the opportunity to point on counting and labeling tasks, they gestured as frequently as the youngest children. Such behavior, however, need not imply that middle level children also gesture primarily for referential purposes on counting tasks since their ability to inhibit gesture when appropriate to do so exceeded that of the youngest group. Rather, it may indicate that gesture and utterance are no longer bound together in counting activities, but that 4-year-old children, unlike more advanced counters, rely heavily on gesture in order to insure an accurate

count. Therefore, in actively pursuing an accurate count, they welcome the opportunity to apply the tracking function of pointing. This position is further supported by the fact that 4-year-old children showed a tendency, though not a significant one, to gesture slightly more often on counting than on labeling tasks on the gesture allowed condition and also to gesture more on counting but not on labeling tasks as compared to the youngest group.

Hypothesis 3--Coordination of Gesturing
to Objects and Names

Another method of inferring the referential function of gesture, as measured by the extent to which verbalization and gesture are bound together, is through the examination of the relative correspondence of names, gestures, and objects. When counting or labeling is accurate, the numerical correspondence between names and gestures is equal to the correspondence between gestures and objects. This is because when names and objects are in one-one correspondence, the relative proportion of gestures to either names or objects is the same. It is only when children count or label inaccurately that differences between name-gesture vs. gesture-object correspondences can be obtained. The direction of these differences indicates whether the child is using gesture referentially or as a means of partitioning objects to obtain an accurate count. If the child is attempting to use gesture as a partitioning and tracking aid to help account for each and every object once and only once, the number of gestures would tend to equal the number of objects. If, on the other hand, gesture is tied to verbalization and the child points in order to reference names to objects without regard for the quantitative

significance of these names, then there should be very little difference between the number of names uttered and the number of gestures utilized.

The latter relationship was characteristic only of the youngest group's performance on both labeling and counting tasks. For this group there was a significantly greater numerical correspondence between the number of names uttered and gestures executed than between the number of gestures used and the actual number of objects in an array. That is, 3-year-old children tended to point referentially each time they uttered a word, but did not attempt to keep track of objects already counted or labeled by pointing to all the objects in an array. It should be noted, however, that this type of performance was evident only on larger set sizes and was more pronounced for counting as compared to labeling tasks.

Several interpretations of the data are possible. First, one may propose that the quantitative understanding of 2- and 3-year-olds is developed for small set sizes and that, therefore, the referencing function of gesture is already transformed into that of a partitioning aid under certain conditions. This proposal is particularly supported by the observation that in the case of set size 3 there was a tendency toward greater correspondence between gestures and objects for the 3-year-old children. It may be suggested, then, that these younger counters may be attempting to track objects with gestures, albeit unsuccessfully.

An alternative explanation, however, seems more plausible based on the finding that performance on labeling tasks was more accurate than performance on counting tasks for the 3-year-old group. This explanation considers the possibility that the use of gesture as a referencing

tool need not preclude the ability to name each and every object once and only once. Such a possibility would particularly be the case when distinctive objects and their unique labels are utilized as they were in this study. Similarly, it may be that even for very young children the first few words at the beginning of a chain of number names are more easily distinguished as individual counting words and that, therefore, accurate referencing of these words to objects is more reliable. This would be part of the early process in which children learn to discriminate between quantitative and non-quantitative events. Such an interpretation, while acknowledging that very young children may have some vague notion of quantity as distinct from other verbal categories, also implies that there is a very basic way in which a one-one correspondence can be attained without any understanding of the counting process itself. Russac (1983) supports this contention in his study of numerosity discrimination with 2-, 3-, and 4-year-olds in which he found that although 2-year-olds did not possess any of the quantitative skills on which they were assessed (rote counting, enumeration, cardinality), they were able to discriminate between small set sizes and transpose this discrimination to new situations involving comparable relative numerosities. He concluded essentially that although number names do not have a quantitative meaning for 2-year-olds, they are able to identify small sets on the basis of perceptual discriminations. This position is supported by others interested in the development of numerosity in infants (Starkey & Cooper, 1980; Starkey, Spelke, & Gelman, 1983). Extending this position to the results of the present study, it may be asserted that the perceptual supports of these small set sizes facilitated

the 3-year-old group's attempt to attach distinctive, though not quantitatively understood, number words to objects in an array in an approximation of one-one correspondence.

Hypothesis 4--Effect of Gesturing on Accuracy

The possibility of maintaining a one-one correspondence between names and objects without an understanding of the counting process itself should have a direct impact on the effect of gesturing on the young child's counting and labeling accuracy. It was observed in this study that very young children labeled objects more accurately than they counted them. That is, they maintained a one-one correspondence between names and objects more consistently on labeling than on counting tasks. This was not the case of the two older groups of children who were equally accurate under both conditions. The 3-year-old group's ability to achieve greater accuracy on the labeling as opposed to the counting condition can best be explained by an examination of the difference in task demands. Although it had been assumed that maintaining an accurate one-one correspondence between labels and objects was based on an understanding of the counting process, in fact the labeling task could be handled successfully without any appreciation of numerical relationships or knowledge of the counting process. Exhaustive labeling of a collection of objects can actually be a much simpler task when not complicated by the constraints of the counting process. In labeling the child need only understand the concept of "all these things" and by applying distinctive verbal labels, remember which objects were already named. The appreciation (or lack of appreciation) of the concepts of "successive iteration "enumeration," "cardinality," and the quantitative values of

the individual number names need have no effect on labeling accuracy. These concepts, however, are necessary for a quantitative understanding of the counting process. The question, though, arises as to whether a quantitative understanding of the counting process is necessary for an accurate count and if not, what conditions contribute to counting accuracy.

One of the interesting, though unexpected, findings of this study was that the 3-year-old children did count, though not label, more accurately when permitted to use gestures. In isolation this finding might indicate that very young children possess sufficient knowledge of the counting process to benefit from the use of gesture. Assuming this knowledge would mean that 3-year-old children's counting activities do not differ qualitatively from those of 4-year-old children who also benefitted from the use of gesture in counting. It also implies that gesture serves the same partitioning function at all ages. Alternatively, one can view these results as another instance in which correct responses are mistakenly accepted as structurally equivalent to one another and in which the observer fails to consider the possibility that the same observable behavior may derive from a variety of thought processes. In this case, one needs to examine the extent to which the counting process can be regarded as a labeling process. Within this context it is possible to understand how an accurate count can be attained without any understanding of quantitative relationships.

For the youngest children in this study, the gesture allowed condition provided an opportunity to count more accurately than on the gesture prohibited trials. This opportunity, however, did not necessarily mean

that gesture was used as a partitioning aid. Rather, their use of gesture probably served as an attention focusing device by means of which the children could more efficiently attach individual number names to particular objects. Gesture then helped the children to break apart a stream of undifferentiated number words and to reference them to one object at a time as they did with non-number words in the labeling process. Because the objects themselves were heterogeneous and familiar items easily distinguished from one another, remembering items already named as separate from those yet to be named was comparatively easy. The children could, thus, produce relatively accurate counts without understanding quantitative relationships. Only an appreciation of the concept of "all these things," as in the labeling condition, was required.

In contrast, for 4-year-old children one may view an increase in counting accuracy under the gesture allowed condition, as compared to the gesture prohibited condition, as strong evidence for inferring that the function of gesture is to partition objects in addition to referencing number names to them. Unlike the 3-year-old children who never achieved high levels of accuracy on either the gesture or no-gesture counting conditions, the 4-year-old children managed to count as accurately as the 7-year-old children only when gesture was permitted. When gesture was prohibited, however, the 4-year-old children could not maintain the same degree of accuracy and tended to omit or repeat objects in a count. That a similar decrease in accuracy did not occur on the no-gesture labeling task, suggests that the labeling accuracy of 4-year-old children was more dependent upon memory and the attachment of unique verbal labels

to individual objects. On the labeling task, then, overt pointing to reference names to objects was not as critical to accuracy as pointing to partition was on the counting task. By comparison, the counting accuracy of these children relied less on the distinctiveness of objects and their labels and more on the quantitative meaning of number. Based on their developing understanding of quantitative relationships, the 4-year-old group was able to adapt the referential pointing gesture to serve as an efficient means of partitioning in order to obtain an accurate count. The external supports available in a non-quantitative labeling situation provided sufficient cues to produce an accurate one-one correspondence between names and objects for the 4-year-old group. However, because the quantitative approach to accurate counting was slower to develop, it initially required the additional external support of overt gesturing. In contrast, the oldest group, having mastered a quantitative understanding of counting as well as the use of covert gesturing to partition and track objects, was unaffected by gesture condition on either counting or labeling tasks. Table 42 contains a summary of the effect of gesturing on accuracy for both labeling and counting tasks at each of the three age levels.

Hypothesis 5--Effect of Array Properties on Accuracy

It was expected that variations in set size and array configuration would affect counting accuracy only in children who had a partial understanding of the quantitative meaning of the counting process. For these children it was expected that small set size and linear display configuration would have a facilitating effect in that they provided external supports for tracking and partitioning efficiency. In contrast, it was

Table 42

Summary of the Effects of the Use of Gesture on Counting
and Labeling Tasks for Each Age Group

Age	Task Type	
	Count	Label
3-year-olds	Counting with gesture is more accurate because gesture serves as an attention focusing device which facilitates the referencing of individual number names to particular objects, i.e., gesture makes counting more like a labeling task	Gesture has no effect on accuracy because the referencing of distinctive names to familiar objects provides a sufficient basis for remembering to name "all these things" with or without the use of gesture
4-year-olds	Counting with gesture is more accurate because gesture serves as a tracking and partitioning aid in the attempt to maintain a one-one correspondence between number names and objects	Same as above
7-year-olds	Gesture has no effect on accuracy because children have mastered covert partitioning techniques in the service of maintaining a quantitatively understood one-one correspondence between number names and objects	Gesture has no effect on accuracy for the same reasons as the youngest and middle age children and possibly because covert partitioning techniques have been adapted to a non-numerical context

expected that for children with no quantitative understanding of the counting process, external supports alone would not induce an understanding of the counting process and, therefore, not affect counting accuracy. Similarly it was expected that for children with a fully quantitative understanding of the counting process, external supports would not significantly affect the internally developed means of obtaining consistently accurate counts. In fact the effect of set size and array configuration in this study varied somewhat depending upon the measure of accuracy utilized.

In general, array configuration appeared to have an effect on both counting and labeling accuracy. Whenever differences in accuracy were observed, linear arrays were always counted or labeled more accurately than disorderly arrays. It was observed, however, that when proportional accuracy scores were used, the effect of array configuration was found for all age groups on both counting and labeling tasks. When difference accuracy scores were used, the same effect was found only for labeling tasks, but on counting tasks, the effect of configuration approached, but did not reach significance. When absolute accuracy scores were used, however, overall effects were observed, but more detailed analysis revealed that this effect was due to age group differences that were consistent with hypothesized expectations. On these results, only the 4-year-old group counted and labeled more accurately on linear than disorderly arrays and no effect due to array configuration was found for 3- or 7-year-old groups. In general, then, the more stringent the accuracy requirements, the more clearly the developmental differences were observed.

If such differences actually exist, then instances in which an absence of these differences was observed could be explained in several ways. First, as with task simplification, one may suggest that lenient scoring requirements so changed the nature of task demands, that the observation of configuration effects across all age groups was merely an experimental artifact. Second, one may argue that some scoring techniques, namely the proportional accuracy scoring of this study, masked real differences. Third, one may seek explanations for the similarity in task performance across ages that reveal a difference in underlying thought processes at the various levels of development. That is, children at different levels may have come to the same results through a variety of means or cognitive processes. This latter explanation will be explored in more detail.

In cases where all children were more accurate on linear than disorderly arrays, the particular supports supplied by linear arrays may have varied somewhat for each age group. The 3-year-old children were probably obtaining near accuracy based on memory for distinctiveness of objects and names. The linear arrangement may have given these children more reliable perceptual cues as to the place of objects that had already been named and referenced. As in the use of gesturing effect, linear arrangements helped these children to deal with the concept of "all these things" without implying any further understanding of the counting process. It also probably helped children to coordinate the series of known number names or labels to the series of available objects in both labeling and counting conditions. In doing this, the linear configuration provided a strong support for the beginnings of a quantitative

approach to counting and the eventual shift in gestural functioning from that of a referencing tool to that of a partitioning aid. It must be stressed, however, that despite the advantages of the linear array as a guide to more accurate association between names and objects, the youngest group did not achieve absolute accuracy even on linear configurations.

For the 4-year-old group, the linear arrangement probably supplied some of the same support as for the 3-year-old group, particularly on the labeling condition. In addition, it also lent itself more readily to the intentional partitioning of items already counted from those yet to be counted. This group was not simply trying to account for all objects by name, but was in addition, using number names to try to mark the relative position of each and every object in a series. That is, 4-year-old children were dealing with items in a series, with each item as part of the whole series, and not merely attaching separate names to unrelated objects as was the case for the 3-year-old group. Because of its perceptual regularities, the linear display facilitated this type of tracking even without the use of overt gestures. The 7-year-old group, to the extent that it was inaccurate at all, also derived the same benefits from a linear arrangement as a perceptual aid to covert tracking and partitioning.

Turning now to the effect of set size on accuracy, the results again reflected somewhat different findings depending upon the type of scoring system used. These differences, however, were found only within the counting condition and only for proportional accuracy scores. The analyses using proportional accuracy scores did not support the

hypothesized decrease in accuracy as set size increased for the transitional or 4-year-old group. Rather, in these analyses set size did affect the 4-year-old group's accuracy, but only on the labeling condition. On the counting condition, the effect of set size was observed only for the youngest, 3-year-old, group, but in the opposite direction anticipated. That is, the youngest children were more inaccurate in counting the smallest as compared to the larger set sizes. The 7-year-old group, as expected, was unaffected by set size. One explanation for these findings is in the nature of this measure of accuracy itself. Because accuracy was measured as the relative difference between the number of objects in an array and the number of names uttered, small errors on small set sizes were relatively more noticeable than small errors on larger set sizes. Particularly for the youngest group this proportional scoring had a marked effect since these children did make errors on very small set sizes and the other groups did not. Although an error of two number names at set size 3 is substantial, the possibility of its occurrence is probably a great deal more likely than an equal sized proportional error at the larger set sizes. For example, in order to make the same size error at set size 12, a child would have to miss by 8 number names. Moreover, to increase inaccuracy at set size 12 as compared to set size 3, a child would have to make 9 or more errors. The problem here appears to be that in attempting to create a balance between errors at the varying set sizes, unrealistic levels of error were required to produce significant results.

Nevertheless, significance was reached on the labeling condition for both the 3- and 4-year-old children, based on this measure. Two effects

elicited by these tasks, however, were possibly at work. First, the labeling errors could have been more pronounced on larger set sizes for both groups due to a tendency to perseverate in labeling objects on these sets. Smaller set sizes, in contrast, lent themselves more readily to accurate memory for names already used and less tendency to repeat names. Second, for the 3-year-old group on the counting task there was a tendency to use a rather narrow range of number names, resulting in proportional counting errors appearing larger on the smallest as compared to the largest set sizes. This narrowness of range, however, was not evident on labeling trials and, therefore, on larger set sizes the magnitude of the youngest group's labeling errors were proportionately greater than on small set sizes. This suggests that under conditions in which memory for names was not taxed beyond its limits, very young children were able to label exhaustively without much error. Once set size exceeded a certain critical point, at around 12 objects, these children, lacking any real partitioning strategy, could not remember which items were mentioned and so began to repeat objects or perseverate.

In contrast to the proportional accuracy results, difference accuracy and absolute accuracy score analyses indicated that both 3- and 4-year-old groups were consistently less accurate as set size increased for both labeling and counting conditions. For the 4-year-old group this would support the notion that their quantitative understanding of the counting process was not fully consolidated and that, therefore, loss of perceptual support on the larger arrays resulted in less accurate counting. In relation to the labeling task, greater accuracy on the smaller set sizes may indicate that 4-year-old children may be beginning

to adapt quantitative strategies to non-quantitative contexts. That is, for these children labeling accuracy on small set sizes may have been due partially to the application of numerical partitioning techniques to deal with a non-numerical activity. It also implies that increased development has led to better memory skills in general as compared to younger children. If this is the case, though, the question arises as to why the 3-year-old group's counting accuracy was also affected by set size. One explanation of the significance of this decrease in difference and absolute accuracy scores with increasing set size is related to the narrow mean range of number names used by this group as discussed earlier. The narrowness of this mean range, somewhere between 5 and 11 names regardless of set size, led to a greater possibility of fortuitously accurate counts on the smaller set sizes and almost no chance of recording accuracy on the larger set sizes. For example, if a child counted to 8 repeatedly regardless of set size, he would be correct at least on two counts of set size 8. If many children did this, some to a count of 5, some to 3, a few to 12, and rarely one to 20, then as a group these children would appear more accurate on smaller than larger set sizes. To some extent this was the case for the 3-year-old children.

On the other hand, many of the youngest children did vary their counts in relative proportion, if not totally accurately, with the varying set sizes. Even if these children were merely assigning names to objects and more objects meant more names, there is still the implication of a basic though undifferentiated sense of quantity. Perhaps these very young children did indeed have some global concepts

of quantity and while they may not yet have understood specific values of particular number names, were beginning to estimate large, medium, and small quantities by the length of a string of number names in comparison to what appeared to be large, medium, and small size arrays of objects. Although the children may not have been aware of it, this underlying comparison may have served as one of the precursors to establishing an understanding of one-one correspondences and numerical values. This notion is similar to Russac's (1983) perceptual discrimination of numerosity and to Starkey' Spelke, and Gelman's (1983) concept of numerical correspondences in infants. This ability probably evolves as the children scan an array and simultaneously recite a stream of number names. Since it takes longer to complete the scan of larger arrays, the children have a longer period during which they continue to recite names and, thus, generate a longer list of number names for larger set sizes. This process, however, should not be confused with a purposeful attempt to maintain a one-one correspondence in counting even as it applies to the smallest set sizes. An assumption of such a goal is inconsistent with the generally low levels of counting accuracy at this level of development as well as with the frequent use of unconventional number lists observed for this group.

A final observation on the effect of set size should be made regarding the performance of the oldest group. Under all scoring methods and for both labeling and counting tasks, the 7-year-old group was consistently accurate across all set sizes. This seems to indicate that once children achieve a quantitative understanding of the counting process, this knowledge can be applied with or without the aid of

external supports. In addition, there is the suggestion that at this level, strategies used for obtaining an accurate count may be applied effectively to non-numerical contexts. It could be argued that a more developed memory for names and possibly a more mature approach to classificatory activities than found in either of the younger groups could have facilitated accurate labeling in the 7-year-old group. However, the efficient separation of items named from those yet to be named, regardless of set size, seemed to underly the performance of the oldest children. To the extent that such separation is part of the quantitative approach to the counting process, these children were able to apply this quantitative strategy to a non-quantitative context. It should be noted, however, that the ceiling effect demonstrated by the oldest group on all tasks may simply have been the result of the limited number of objects utilized in this study. Substantially increasing set size may have significantly altered this group's performance.

Hypothesis 6--The Effect of Gesturing on
Speed of Counting

It was hypothesized that children who were beginning to use gestures in order to partition an array for counting, but who had not yet perfected the technique, would require more time to count arrays when gesturing was allowed. This was in contrast to referential pointers who were assumed to point simultaneously as they uttered counting names and, therefore, required no extra time to coordinate their efforts and also in contrast to more advanced counters who were expected either to gesture more automatically for partitioning purposes or not gesture even when allowed to do so. In fact, gesturing did not influence the amount of time taken to complete a count at any age.

One explanation for this finding is that the function of gesture in counting does not vary over development nor does facility improve in the use of gesture. That is, children of all ages would gesture to partition and do it fairly effortlessly. This explanation, however, does not fit well with the other data of this study and, in addition, is inconsistent with other studies that concern themselves with problems of motor coordination in the counting behavior of very young children (Gelman & Gallistel, 1978).

An alternative explanation is that referential and partitioning gestures take equally long to execute and that it is an error to assume that referential gesturing occurs simultaneously with verbalizations or that counting without gestures reduces the child's concentration and motivation so as to render the count a perfunctory one. This explanation suggests that working without either type of gesture places a strain upon the capacities of the 3- and 4-year-old children. That is, it takes effort and, therefore, time to reference a word to an object without the aid of pointing just as it takes time to mentally partition an array without the use of overt tracking gestures. This time and effort then balance out with the time and effort needed to coordinate gestures to objects or words in the gesture allowed condition. This is consistent with the data reported here in that the two younger groups were slower counters than the oldest group under both gesture and no-gesture conditions.

A third explanation of the failure to distinguish between time needed on gesture and no-gesture counting conditions, not inconsistent with the previous one, is that speed of counting does not depend upon

how long it takes to make and coordinate gestures, but that it varies more as a function of non-gestural variables such as verbal fluency and visual discrimination. This explanation is again consistent with the data obtained that indicated that the oldest children were significantly faster counters than either of the two younger groups regardless of gesture condition and that only the youngest children took longer to complete disorderly as opposed to linear arrays. While it is reasonable that older children should be able to generate number names, connect names to perceived objects, and locate objects in a disorderly arrangement more rapidly than younger children, variations in these capacities could and probably did effectively mask any potential differences for 4-year-old children in speed of counting based on gesture condition.

Hypothesis 7--Gestural Patterns on the Counting Task

If in fact the function of gesture in counting activities undergoes a shift from that of a referencing tool to that of a partitioning aid, then this transformation ought to be reflected in the relative efficiency of the children's gestural patterns. That is, the direction in which a child points should reflect the purpose that this pointing serves. A child who scatters his/her gestures randomly from one object to another in an array would probably not be trying to keep track of objects already counted, but rather would be more involved in naming objects as they caught his/her interest. On the other hand, a child who methodically traces the periphery of a group of objects or points to objects row by row, would appear to be attempting to maintain his/her position within a collection in order to avoid skipping or repeating items in a count. Gelman and Gallistel (1978) argued that systematic

counting from one item to the next reflected an understanding and was guided by knowledge of a partitioning rule directed at accounting for each and every item once and only once. They claimed that the very young children they observed counting did in fact move systematically from one item to the next and hardly ever skipped around or went back and forth in an array. In contrast, in the present study differences in types of gestural patterns and counting accuracy were observed among the three age groups investigated.

The 3-year-old children, while not completely consistent, tended to favor a random direction of pointing more often than either of the two older groups and also produced mostly inaccurate counts. This seems to support the hypothesis that children at a prequantitative level use pointing in order to reference number words to objects, as they would with any other words, while going through the motions of a counting activity. In contrast, the 4-year-old group in this study achieved a high degree of accuracy when pointing was allowed, showed a marked decrease over the 3-year-old group in the occurrence of random gesturing, and almost always applied their gestures in a linear or at least orderly direction. This strongly suggests that these children gestured for the purpose of partitioning objects in order to obtain an accurate count and that they were able to do this because they were impelled toward greater efficiency through their increased quantitative understanding.

The progression in this shift of gestural function is further emphasized by the performance of the 7-year-old group of children in this study for whom overt pointing had become less important, but who,

nevertheless, used only linearly directed gestures when gesturing was used at all. The more mature quantitative understanding of this group was reflected in their ability to maintain an accurate count in the absence of external supports such as gesturing. Nevertheless, to the extent that they did apply gestures, the orderliness with which they were executed indicated that for this group gesture functioned as it did for the 4-year-old group. That is, it served as a partitioning aid as distinguished from the haphazard pointing of the 3-year-old group for whom pointing served only a referential function.

Hypothesis 8--Quantitative Gestural Techniques
on the Labeling Task

Based on the assumption that fully consolidated forms of knowledge lend themselves to generalizations to new cognitive domains, it was expected that quantitatively advanced children would apply numerical gestural techniques to a non-numerical labeling task. This study did not lend any direct support to that argument, in part because the 7-year-old children seldom used overt gestural techniques in the labeling task. To the extent that overt pointing on labeling tasks did appear for this group, however, there was almost a total absence of gestural techniques that could be considered clearly quantitative in intention. Rather, particular techniques could have been classified as either numerical or referential.

The failure of this study to elicit the application of numerical gestural techniques to the labeling task, however, does not necessarily suggest a lack of transfer of quantitative knowledge to a new context. The high level of labeling and counting accuracy of the oldest group

implies that some systematic approach to both tasks was utilized. It is possible that covert grouping or partitioning strategies having their roots in the understanding of the counting process were adapted to function in a non-numerical context. Conversely, it must be remembered that under the conditions of the present study, involving the use of distinctive heterogeneous objects, the labeling condition was actually the easier of the two types of tasks to perform. Therefore, even if these older children had the necessary knowledge to apply advanced partitioning gestural techniques to the labeling task, the extra effort to do so would probably have been regarded as unnecessary. In addition, it is unfortunate that the counting task itself did not demand grouping or addition strategies for successful completion and so older subjects were not given an opportunity to demonstrate knowledge of these strategies. Without knowing whether these strategies were operating in a numerical context, it is impossible to determine the extent of their transfer potential to other contexts.

If the tasks were more difficult, however, the absence of observable numerical gestural strategies on the labeling task might have been predicted. It may be that more advanced numerical concepts beyond the counting process itself are necessary to stimulate the generalization of strategies to a new context. That is, more advanced numerical concepts including knowledge of arithmetic operations beyond the successive iterations and summations of the counting process may have been necessary for the adaptation of more quantitatively advanced gestural techniques to the labeling task. This position is supported by early evidence in the Beckwith and Restle (1966) study in which only

the college age subjects and not even the 9-year-old children in their sample were observed to utilize grouping and addition strategies in their counting activities. In the present study, the children in the oldest group were even younger than age 9 and were not evaluated on any numerical tasks going beyond the requirements of counting. It was not possible, therefore, to determine directly whether these particular children had the necessary background for applying more advanced quantitative concepts to the labeling task, although the Beckwith and Restle study suggests that they did not.

One final point, however, is that although positive evidence may not exist, one may still make inferences based on the absence of negative instances. The 7-year-old group in this study displayed a total absence of gestural techniques that had a completely non-quantitative function, such as pointing into the air, making broad sweeping gestures, or moving objects haphazardly as they were labeled. Interestingly, these techniques were present to some extent in the labeling efforts of both the younger groups. It is possible to conclude, therefore, that although full quantitative understanding of the counting process does not necessarily facilitate the application of quantitative gestural strategies to non-quantitative activities, it does reduce the likelihood of using gesture functionally in ways that impede obtaining an accurate one-one correspondence between labels and objects.

Conclusions

In general, children at each of the selected age groups fit into the level of quantitative understanding predicted for these groups and did or did not utilize gestures as expected for their levels. To some extent, however, children at all ages performed somewhat precociously and demonstrated more efficiency and greater accuracy than had been

anticipated. It is suspected that to a large extent the specific materials utilized determined the type of behaviors that were observed. Object heterogeneity made all tasks simpler and probably facilitated the ease with which youngest subjects could transform the task demands from one of counting to one of labeling. In addition, it facilitated memory for objects named from those yet to be named for all children. Moreover, it reduced task difficulty sufficiently to support covert gesturing efforts so that 4-year-old children counted with some efficiency with or without gestures and the 7-year-old children attempted to gesture less often than had been expected based on previous research.

Within the limits of this study, nevertheless, it was concluded that very young children lacked a quantitative understanding of the counting process, but, nevertheless, could distinguish between numerical and non-numerical contexts. This is based on the observation that all of the 2- to 3-year-old children consistently used number names for counting and used non-numerical words for labeling tasks. In addition, these children probably had some global sense of large and small quantities, and could understand broad quantitative concepts such as "all these things" and "oneness." This is based on the observation that to some extent even 3-year-old children used more number words as set size increased and were able to benefit from external supports such as linear configurations and the utilization of gesture. It was also concluded that these children pointed in order to reference names to objects on both counting and labeling tasks. This was based on the fact that the 2- to 3-year-old children had a greater correspondence between names and gestures used than between gestures used and the number of objects in an

array. It was also based on the observation that the 2- to 3-year-old children used a random pattern of pointing more than the other groups and that this group had difficulty inhibiting gestures when verbalizing.

For the very young child, labeling arrays with non-numerical words posed an easier task than counting arrays because of the additional external supports that the former provided, such as more easily remembered distinctive verbal labels and the sense of each object as an individual thing apart from its relationship to a group of things. To the extent then that particular materials and array properties enhanced the child's ability to assign distinct number words to particular objects, i.e., to make counting more like labeling, the very young child was able to maintain a closer correspondence between number words and objects.

As children developed and they began to understand the quantitative significance of counting, they extended their concepts of "all these things" to "each and every one of these things, one time each." This conclusion is based on the observation of the improved counting accuracy of the 4- to 5-year-old group as compared to the 2- to 3-year-old group. Nevertheless, during this transitional period children's ability to maintain a one-one correspondence between names and objects varied with stimulus conditions. Smaller set sizes, linear arrays, and the utilization of gestures had a facilitating effect upon counting and labeling accuracy. Initially the children probably referenced each and every object by means of pointing gestures and in doing this gradually adapted the pointing gesture to function as a tracking and partitioning aid. This adaptation again was facilitated by external supports such

as linear configuration and aided by memory for objects already accounted for.

While adapting overt pointing gestures to this function, the child was simultaneously beginning to develop covert forms of gesturing in order to partition. Therefore, although gesturing was quite important in enabling the 4- to 5-year-old child to obtain an accurate count, the intention to be accurate persisted with or without the use of overt gesturing. To some extent then this child was able to utilize covert partitioning techniques and so a child with partial understanding of the counting process could be a fairly accurate counter with or without gestures, although he/she was a better counter when permitted to gesture.

The oldest children in this study were accurate counters and labelers with or without the use of gesture. Because they did not spontaneously gesture with great frequency, it is difficult to form any conclusions about the nature of gesturing activities in quantitatively advanced children. The only point that can be made with certainty is that these children gestured as well covertly as they did overtly and to the extent that overt gesturing did occur, it served a partitioning function. Further investigation of older children on tasks that pose greater difficulty, such as using larger set sizes and/or homogeneous arrays, would have to be conducted in order to determine whether children who fully understand the quantitative relationships of the counting process use more advanced grouping gestural strategies and, if so, the extent to which these strategies are applied to non-quantitative contexts.

Educational Implications

There is a trend among some contemporary educators and parents to try to accelerate cognitive development through the introduction of academic instruction during the preschool years and even in infancy. The assumption behind these efforts is that there are no limits to children's potential for conceptual understanding and that the earlier that concepts are grasped, the greater the likelihood of success in coping with later intellectual challenges. In contrast, the position of this paper, largely supported by the results of its investigation of the use of gesture in counting activities, has been that precocious performance does not necessarily reflect mature cognitive understanding. Rather, it was observed that even when outward behavior seems to conform to task demands, an examination of children's errors may reflect different underlying thought processes. This observation is consistent with the principle that there are qualitative differences in children's thinking over development and that children understand and interact with their environment within the framework of their existing cognitive capabilities.

In terms of educational programs, then, behavioral manifestations that appear to conform to instructional objectives may not necessarily indicate that children have attained these objectives. Instead, the belief that all things can be taught to all children may lead to an overestimation of the kinds of concepts that are being mastered by young children. In the area of number concept development, as well as in any other cognitive domain, careful consideration must be given to matching the level of instruction to the actual level of children's reasoning capacities.

An example of the kind of pedagogical error that occurs when instruction surpasses cognitive development is found in the humorous story of the child who comes home and asks his/her parents, "Where did I come from?" The parents, of course, anxious to respond sensitively to their perceived concern of the child, offer a detailed explanation of human reproduction and the birth of babies. At the conclusion of the lesson, however, the child is not satisfied and repeats the question adding, "Yes, but Eli and Hannah come from New York. Where do I come from?" The point of this anecdote, then, is really that as educators and parents we should not give children more information than they need or can deal with, but must work with concepts as children use them. From this starting point instruction can proceed.

In terms of number concept education, the results of this study suggest several approaches, beginning during the preschool years, for guiding children toward a quantitative understanding of the counting process within the framework of their existing conceptual development. First of all, it was found that children even between the ages of 2 and 3 do have some sense of number names as distinguished from other categories. However, these names are not initially clearly separated from one another and are not accurately applied in a one-one correspondence to a series of objects. A primary goal then of teaching number concepts to preschool children is to increase the accuracy with which number names are used in one-one correspondence with objects, apart from the purpose of obtaining a cardinal value and regardless of what the meaning of these names may be for the children.

One of the findings of this study relevant to this goal was that for young preschool children pointing gestures made counting more like any other labeling task. Gesturing, then, facilitated distinguishing between each number name so that separate words could be assigned to individual objects in an array. This process can be encouraged prior to the understanding of cardinal value by teaching more efficient labeling strategies for referencing unique number words to particular objects once and only once in a count. One way of doing this is to use heterogeneous objects in arrays to be counted so that the uniqueness of each object complements the distinctiveness of the verbal numerical labels. The use of heterogeneous objects in the present study was found to facilitate counting accuracy for young preschoolers compared to the results of this age group in a previous study using only homogeneous arrays (Saxe & Kaplan, 1981). Another technique, borrowing from Gelman and Gallistel's (1978) order irrelevance principle, is to provide children with multiple opportunities for counting the same array when the position of objects within arrays is shifted from count to count. This should help children to realize that even though objects may receive a distinct name in each count, no particular name always belongs to a particular object. This step is one that begins to draw a distinction between labeling as a non-numerical activity and counting as a form of numerical reasoning. Once children master these activities with heterogeneous arrays, practice with homogeneous arrays should follow in order to further distinguish between counting and non-numerical verbal labeling processes.

Another strategy for developing pre-cardinal number concepts in a counting context might be through the use of computerized instruction that maximizes the natural tendency of 2- and 3-year-old children to use pointing gestures. This type of instruction, while beginning with the child's existing conceptual capabilities could go beyond them, not to demonstrate precocious performance, but more along the lines of Vygotsky's (1978) conception of the "zone of proximal development." The zone of proximal development refers to those capacities that are in the process of maturing. In this conception, the child can progress from the point of his/her actual developmental level, as measured by what the child can do without any assistance, to a potential level of development achieved under the guidance of a more mature collaborator. In the case of the use of computerized instruction in counting activities with preschoolers, the computer program would serve as the more mature collaborator.

For example, a display screen might present a linear series of uncolored circles and the child would have to press a button one time for each circle. At each press of the button, one circle would become colored until all the circles were filled in. After the final circle was filled in, a bell or beep would signal the child that further pressing was unnecessary and that the row was complete. Alternatively, the screen might display a series of different uncolored shapes and the child be required to press a button corresponding to each shape until all objects in the array were colored. This kind of externally induced coordination of gesture to object would rely on the child's natural tendency to use pointing gestures and at the same time force the child

to maintain a one-one correspondence of gestures to objects. Ideally the coloring of the circles or other forms would be accompanied by a computerized voice counting simultaneously, but even without such accompaniment, the child could be instructed to count aloud as he/she pressed the button. Given that the findings of this study indicated that younger children tend to have a high correspondence between words and gestures regardless of counting accuracy level, this type of coordination of word, gesture, and visual change in objects should increase the likelihood of assigning single number names to each and every object. The visual displays, of course, should vary and increase in length and eventually consist of disorderly configurations in order to teach the child to use pointing gestures most efficiently. On disorderly arrays, objects would automatically become colored in the spatial order that would be most appropriate for insuring an accurate count.

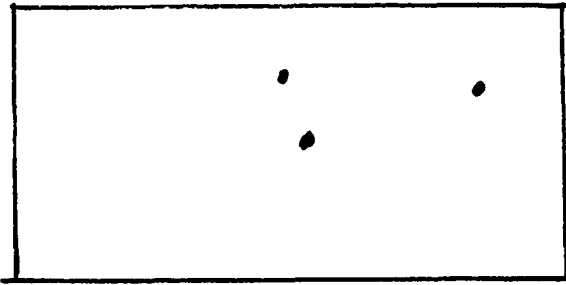
Another format might be to present the child with a visual display of objects or shapes and have him/her press a button the corresponding number of times. If the child was correct, the computer would "ding" and if the child was in error, the computer would "buzz." Again the child should be encouraged to recite number names in time to the button pressing.

Once these techniques of successive iteration are mastered, the young preschool child might be exposed to a mechanical application of cardinal value in order to begin to introduce the concept that a number name stands for the summation of all items and all previously stated number names used for an array. For example, after the last item in

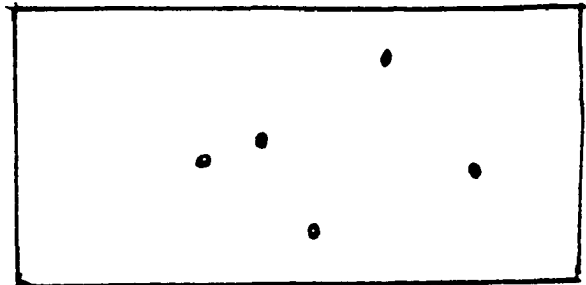
a series is colored, a computerized voice might repeat the final number name as the object color flashes on and off. Another possibility is that the child repeatedly press a button until he/she produces a numerically corresponding second array that appears above or below the original one. The computer would automatically position the objects so that they were aligned with the first array and produce a sound signaling when the reproduction was complete. For older children, who had already mastered a mechanical sense of cardinal value (i.e., the last number uttered answers the question of "how many?") increased practice in duplicating arrays not in perceptual correspondence could be utilized. For example, a linear sample array might be displayed and the child would press a button to generate a numerically corresponding disorderly array, or vice versa. Whatever the specific format, the point is that through computerized instruction, children could use those concepts and strategies that are familiar to them and at the same time apply their knowledge to slightly more advanced counting techniques and numerical problems. This approach, while allowing for early exploration of academic areas, recognizes that children's potential for conceptual understanding is not limitless and that the same outward forms of behavior may have different cognitive underpinnings.

APPENDIX A

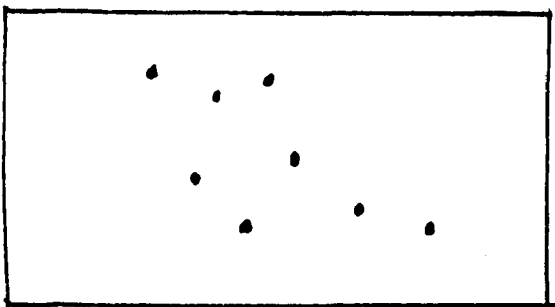
Arrangements of Disorderly Arrays



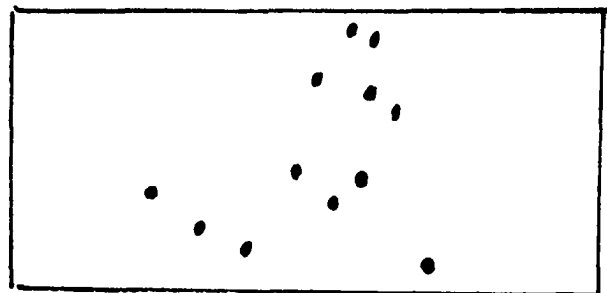
Set Size 3



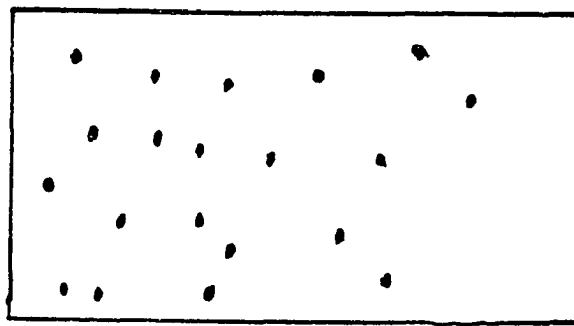
Set Size 5



Set Size 8



Set Size 12



Set Size

APPENDIX B
Criteria for Determining Gestural Patterns

Disorderly Arrays

Set Size 3

Linear--goes from left to right or right to left in one direction only, beginning at end points with no skipping of objects.



Proximal--starts at point closest to self (midpoint) and then moves to adjacent items without skipping any objects.



Random--points to same object or objects more than once while eliminating other objects or makes sweeping gesture with an inaccurate count or points to non-objects.

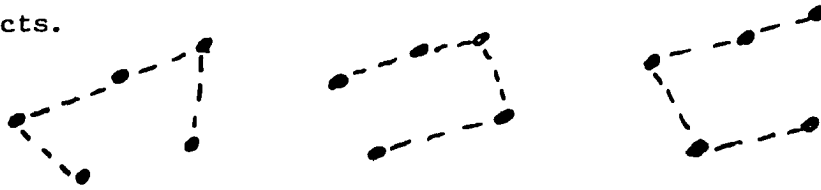
Tracking without gestures--perfect accuracy, but points to 33% or less of the objects.

Set Size 5

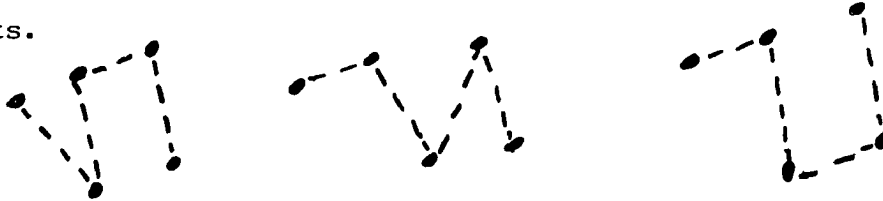
Linear--points in the direction indicated in diagram, going either from left to right or right to left without skipping any objects.



Peripheral-- points in the following patterns without skipping any objects.



Proximal--points in the following patterns without skipping any objects.

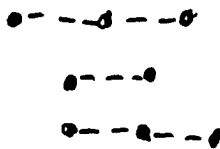


Random--makes one or more non-adjacent points or repeats points to one or more objects while eliminating other objects or makes sweeping gesture with an inaccurate count or points to non-objects.

Tracking without gestures--perfect accuracy, but points to 33% or less of the objects.

Set Size 8

Linear--points in the direction indicated in diagram, going either from right to left or left to right.



Peripheral--points in the following pattern without skipping any objects.



Proximal--goes from one to another adjacent object in such a way that neither linear nor peripheral patterns appear; one non-adjacent point allowed.

Random--makes at least two non-adjacent points within proximal pattern or repeats points to one or more objects while eliminating others or makes sweeping gestures with an inaccurate count or points to non-objects.

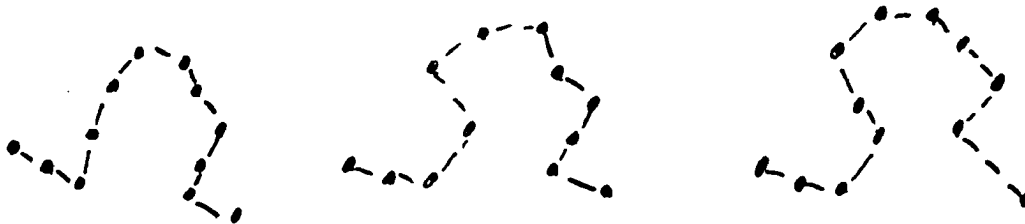
Tracking without gestures--perfect accuracy, but points to 33% or less of the objects.

Set Size 12

Linear--points within the three groups in the diagram in an orderly fashion without skipping any objects.



Peripheral--points in the following patterns without skipping any objects.



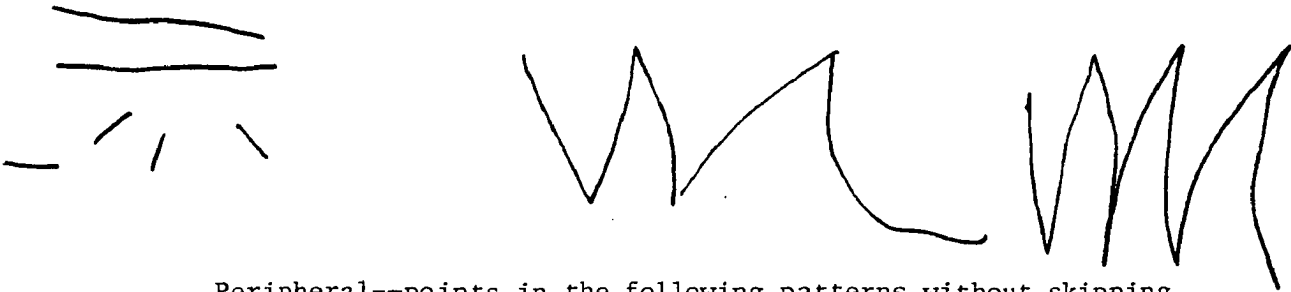
Proximal--points to adjacent items only with no more than two exceptions such that neither linear nor peripheral patterns appear.

Random--points to at least three or more non-adjacent items or points more than once to two or more items while omitting others or uses sweeping gestures with an inaccurate count or points to non-objects.

Tracking without gestures--perfect accuracy, but points to 33% or less objects.

Set Size 20

Linear--points in the following patterns with no more than four items off the pattern and without skipping any objects.



Peripheral--points in the following patterns without skipping any objects.



Proximal--points to adjacent items primarily with no more than four exceptions, such that neither the linear nor peripheral patterns appear.

Random--points to at least five non-adjacent items or four repeats plus four omissions or points to less than 50% of the objects in a grossly inaccurate (off by 33% or more) count or makes sweeping gestures with an inaccurate count or points to non-objects.

Linear Arrays

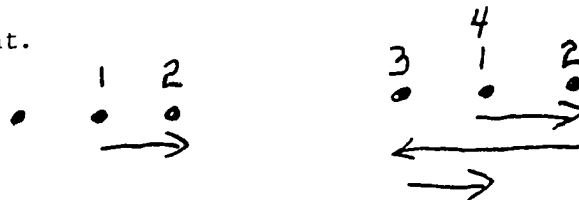
Set Size 3

Linear--begins at either end and points to one item next to another in a single direction with no skips.

Partial linear--begins at either end, but with one reversal and/or skip.



Non-linear--begins in middle of row or two or more reversals or points to non-objects with an inaccurate count or two skips with an inaccurate count.



Tracking without gestures--perfect accuracy, but points to 33% or less of objects.

Set Size 5

Linear--same as set size 3.

Partial linear--begins at either end, but with up to two reversals and up to two skips.

Non-linear--begins in middle of row or three or more reversals or three or more skips with inaccurate count or makes sweeping gesture

with an inaccurate count or points to non-objects.

Tracking without gestures--same as set size 3.

Set Size 8

Linear--same as set size 3.

Partial linear--begins at either end, but with up to two reversals and up to two skips or no reversals and up to three skips.

Non-linear--same as set size 5, but four or more skips with an inaccurate count.

Tracking without gestures--same as set size 3.

Set Size 12

Linear--same as set size 3.

Partial linear--begins at either end, but with up to two reversals and up to three skips or no reversals with up to five skips.

Non-linear--begins in middle of row or three or more reversals or six or more skips with inaccurate count or makes sweeping gesture with inaccurate count or points to non-objects.

Set Size 20

Linear--same as set size 3.

Partial linear--begins at either end, but with up to two reversals and up to five skips or no reversals and up to eight skips.

Non-linear--same as set size 12, but with nine or more skips with an inaccurate count.

Tracking without gestures--same as set size 3.

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