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City University of New York PH.D. 1985

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A COMPARATIVE AND DEVELOPMENTAL ANALYSIS OF CONGENITALLY BLIND AND SIGHTED CHILDREN'S COUNTING

by

STEPHEN SICILIAN

A dissertation submitted to the Graduate Faculty in Educational Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1985

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.

4/29/85
date

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Abstract

A COMPARATIVE AND DEVELOPMENTAL ANALYSIS OF CONGENITALLY BLIND AND SIGHTED CHILDREN'S COUNTING

by

Stephen Sicilian

Advisor: Professor Geoffrey Saxe

The present study investigated the development of tactile-motor strategies that congenitally blind children use to facilitate the accuracy of their counting and compared their counting performance to that of a group of sighted children matched for counting proficiency. The analysis of tactile-motor strategies identified three dimensions of strategic behavior: preliminary scanning, count organizing and partitioning. A sequence of steps were identified in children's progress toward developing fully articulated endpoint strategies for each dimension. Additional analyses were performed to investigate consistency of strategy use across task conditions and interrelationships between the three strategic dimensions.

A comparative analysis of counting errors of blind and sighted subjects was used to determine the nature of differences between the two groups. Although blind subjects were delayed in the development of counting abilities

relative to sighted subjects, the findings of the present study suggest that both blind and sighted subjects progress through similiar steps in the development of systems of numerical representation. Beginning counters in both blind and sighted groups made errors suggesting a lack of understanding of the logic underlying the construction of one-to-one correspondences. More proficient blind and sighted counters no longer made these "conceptual" errors. Their errors reflected difficulty mastering perceptual-motor skills. Variation in the dominance of particular perceptual-motor errors found between blind and sighted subjects suggests that the difference between these two groups lies in the kinds of obstacles encountered when implementing conceptual knowledge through different perceptual-motor systems.

Acknowledgments

I would like to thank a number of people who provided the guidance and assistance which enabled me to complete this research. First, I would like to thank Geoffrey Saxe who as my teacher encouraged my interest in child development, as my employer provided me with the experience from which I developed my research skills, and as my advisor provided direction, critical recommendations and encouragment in conducting the present research. I particularly thank him for remaining my advisor after leaving the Graduate Center to accept a position at U.C.L.A., despite the demands of his new responsibilities.

I would like to thank the other members of my committee, Joseph Glick and Sylvia Scribner, for offering theoretical suggestions and encouragment at various points in the evolution of my research. I particularly thank Joe Glick for accepting the position as acting chairman in Geoffrey's absence.

I would like to thank a number of agencies who cooperated in my search for subjects. These include: The Lighthouse of New York Association for the Blind, Camp Wapanacki, Vermont, Department of Pediatrics University of Massachusetts, Connecticut Department of Human Resources, New Jersey Commission for the Blind, New York City Public Schools, Perkins School for the Blind, Park Avenue Methodist

Nursery School, and St.Hilda's and St.Hugh's School.

A large number of students and friends offered both academic and emotional assistance. I would particularly like to thank Warren Cohen who has been an advisor, collegue and most of all friend throughout my years at the Graduate Center. He was always available whenever I needed an insightful critic or supportive friend. I would like to thank Emily Guile for her critical advice, and long hours of editing when she had much of her own work to complete. I particularly thank her for her unfailing encouragement and emotional support when I needed it most. I would like to thank Luise Eichenbaum who as my therapist and friend provided understanding and support when it was needed and helped me to learn much about myself from my ambivalence and frustration along the way.

There were many friends both in and out of the Graduate Center who have provided both intellectual and emotional support throughout my eight years of graduate study. I would like to thank Jeffrey Ringle, David Nemiroff, Roger Okon, Patricia and Joan Grey, Patricia Sicilian, Janet Welch, Rochelle Kaplan and Andy Leon.

Finally, I would like to thank my family. My parents Leonard and Veronica Sicilian have provided me with both emotional and financial support, and the desire to pursue academic interests. My sister Donna Sicilian has expressed much interest and encouragment. I particularly thank my brother James Sicilian who has shared my goal throughout many years of study, offering his understanding and above all constant and unwavering support both emotionally and at times financially.

Table of Contents

III Results and Discussion I

IV Results and Discussion II

LIST OF TABLES

Table Page

CHAPTER I

Introduction

Children's counting abilities have been the focus of a considerable amount of research in recent years. Researchers have examined various aspects of counting and have produced a number of competing views of how children develop counting abilities. One aspect of counting which has been the focus of considerable controversy concerns the numerical significance of young children's counting. According to Piaget (1952), a mature understanding of number is based on an understanding of the logical relations of class and order. During his investigations of children's number concepts Piaget found that children do not fully understand these relations until they are approximately six years of age. He concluded that since younger children do not understand the logical relations underlying the concept of number, their counting cannot have any numerical significance.

Alternatively, Gelman and Gallistel (1978) suggest that even young children have some understanding of the "logical principles" that constitute the counting system, but have difficulty mastering the perceptual-motor skills necessary to implement that understanding. According to this position, children as young as two years of age are able to use their counting to represent quantity.

Saxe (1977) has proposed a third intermediate position, suggesting that children's understanding of counting undergoes a qualitative shift during development. According to this model, young children's counting is part of a naming activity that has little, if any, numerical significance. As children develop, they progress through several phases in which they gradually construct and coordinate the cognitive operations which underlie the counting system. With this development they come to view counting as a means of representing quantity and to recognize the need for accurate one-to-one correspondences. This shift provides the conceptual development necessary for children to imbue their counting with numerical meaning.

A second issue addressed by research on counting concerns the development of counting strategies used to facilitate counting accuracy, e.g.: pointing (Saxe, 1977; Saxe & Kaplan, 1981); the use of physical characteristics of individual objects (Schaeffer, Eggleston, and Scott, 1974); and the use of configurational arrangements of arrays (Beckwith & Restle, 1966; Shannon, 1978). Shannon (1978) suggests that children's developing perceptual capacities provide the basis for the development of more efficient strategies. Saxe (1977), on the other hand, suggests that a shift in children's conceptual understanding of counting from a non-quantitative referencing system to a system of numerical representation motivates them to create strategies to assure the accuracy of their counting.

While most of the research in children's counting has focused on development in normal, middle class children living in Western cultures, several researchers (Glick, 1975; Harkness, 1980) have questioned the adequacy of developmental models based exclusively on observations of such homogeneous populations. These researchers argue that studying development within a single population obscures variations in cognitive and emotional behavior and leads to the prominance of nativist theories present in the field today. Studies of comparative populations such as non-western cultures and children with developmental abnormalities increase our awareness of cognitive and emotional variation as well as the many internal and external variables responsible for that variation.

Glick (1975) suggests that developmental models determining the relative impact of biological and cultural factors on development must be based on studies that meet two requirements. First, there must be variability within each factor so that contrasts between different values of a factor may be compared; second, there must be separability of factors, in such a way that the factors do not always co-vary but can be pitted against one another. Using a review of previous research, Glick demonstrates how cross cultural studies satisfy these two criteria and provides data illuminating the contribution both social and environmental variables make to the development of perceptual and cognitive abilities.

Research with developmentally disabled children is a second way of isolating the influence of factors regularly confounded in normally developing, middle class children. Researchers have investigated the effects of sensory loss (Fraiberg, 1977), language deficits (Kamhi, 1981), and mental retardation (Brown & Campione, 1977) on cognitive and emotional development. Fraiberg (1977) made a significant contribution to our understanding of biological and experiential factors in motor development. Studies of motor abilities in "normal" infants have suggested that development of gross motor activities such as sitting, creeping, standing, and walking are primarily controlled by maturation of the bones and muscles of the child's body. These studies imply that experience is important only as a means of refining motor activities. In her study, Fraiberg (1977) found that blind children (who had no other disabilities) developed postural abilities such as sitting and standing alone at normal rates. However, they were markedly delayed in the development of self-initiated mobility activities such as creeping and walking alone. She attributes this delay in self-initiated activities to blind children's restricted awareness of visual incentives during the first year of life. Thus, Fraiberg's (1977) study demonstrated the importance of experience in the development of abilities often considered to be innate.

The purpose of the present study was to conduct a developmental and comparative analysis of blind and sighted children's counting abilities. The goals of the developmental analysis were: first, to identify and describe developmental differences in the types of counting strategies used by blind childen at different ages and levels of counting proficiency; second, to determine if there is evidence of conceptual errors in children's counting; and third, to determine if there is a relationship between conceptual errors and the development of strategic behavior. The comparative analysis consisted of comparisons between the error patterns of blind and sighted subjects. The goals of the comparative analysis were: first, to determine the existence and nature of differences in either conceptual or implementation errors between blind and sighted subjects; and second, to use the findings on differences in implementation errors between blind and sighted subjects to test the position that many of children's counting errors are related to difficulty they have mastering perceptual-motor skills. Studies cited in the literature review presented below suggested hypotheses for the present study which address each of these goals.

The following literature review is organized into three sections. The first section reviews studies on the development of numerical cognition in sighted children. The second section reviews studies on blind children's use of tactile perception and differences between visual and tactile perception. The third section attempts to combine these two areas of research and describe how they led to the specific hypotheses tested in the present study.

Development of Numerical Cognition: Research with Sighted Children

Several issues addressed by research on children's counting abilities are relevant to the present study. These issues include: competing views on the numerical significance of children's counting; findings concerning the use of visual-motor counting strategies in sighted children; and the use of counting errors as a means to determine children's understanding of counting.

Numerical Significance of Children's Counting

Several researchers have suggested competing positions on the numerical significance of children's counting. Piaget (1952) suggested that young children's counting involves the rote recitation of a series of number words having no numerical significance. Other researchers such as Gelman (Gelman, 1972: Gelman & Gallistel, 1978) disagree with Piaget and suggest that the counting of children as young as two indicates they have an understanding of the logic underlying counting and are able to use their counting to represent number. The following discussion summarizes both positions and reviews other research bearing on this issue.

Piaget (1952) presented children with several number-related tasks including his number conservation task. Based on his subjects' performance he suggested that children advance through a series of stages in the development of a mature concept of number. These stages differ qualitatively from one another and reflect advances in children's development of logical concepts of class and order. Children at the first stage base their judgments of number on spatial characteristics of arrays such as their length and density. If a child at this stage is presented with two arrays of objects and one array is longer than another the child will judge the longer array as containing more objects. When children reach the second stage they establish the equivalence of two sets based on one-to-one correspondences. However, if the perceptual characteristics of one set are changed, children falter and judge the longer or more dense array to contain more objects. Finally, children at the third stage understand that spatial changes in the array do not effect the numerosity of a set. These children recognize that a change in the length of an array is compensated for by a change in its density. Piaget suggested that this third and final stage is the hallmark of a mature understanding of number and indicates that the child is able to consider individual objects as having both cardinal (class) and ordinal (order) significance. Piaget suggests that until children achieve this final stage of development, their counting cannot have any numerical meaning. As further support for his position, Piaget noted that his stage one and two subjects often counted arrays correctly and then went on to base their judgements on spatial characteristics of the arrays.

Gelman's (Gelman, 1972; Gelman & Gallistel, 1978) position is different from that of Piaget. According to her position, even the counting of very young children demonstrates an understanding of its numerical significance. Gelman defined several logical principles that underlie the counting system. These principles include:

The stable order principle: the child must have a stably ordered list of number words committed to memory.

The one-to-one principle: each item in the array must be paired with one and only one number word. This principle requires the coordination of two component processes:

Partitioning:	the child must select one object at a time from the array, while also separating objects already counted from those still to be counted
Tagging:	the child must select one numeral at a time from the stable list

The cardinal principle: the child must attribute special significance to the last numeral stated, in that, it refers to the cardinal value of the set as a whole.

The abstraction principle: any array or collection of entities can be counted.

The order irrelevance principle: the order in which items in a collection are counted is irrelevant.

According to Gelman's model the above principles are organized into a scheme which directs the young child's counting. Based on her analyses of a series of studies of the counting behaviors of children between the age of two and five Gelman suggested that children as young as two have an understanding of each of her counting principles and are able to use counting to represent number. According to Gelman's position, the development of counting abilities between the age of two and five involves only the perfection of the perceptual-motor skills necessary to implement these principles, rather than a qualitative change in the conceptual understanding of number as Piaget argued.

Results of a study by Schaeffer, Eggleston and Scott (1974) call into question the view that young children understand the numerical significance of counting. This study investigated children's ability to extract the cardinal value of an array from their count. Children were asked to count an array of objects. After they had completed their count the experimenter covered the array and asked "Now I've covered them up. How many chips are there under the paper?" The findings indicated that three to four year old children who were able to accurately count arrays of one to seven objects were nonetheless unable to give accurate cardinal responses. These children either recounted by pointing to remembered portions of the hidden chips or named a number other than the last one counted.

While the above findings agree with Gelman's in terms of children's ability to count arrays, they indicate that children as old as 4 still have some difficulty when asked to extract the cardinal value of an array under certain conditions. This finding suggests that perhaps children's understanding of the numerical significance of their counting may still be forming between the ages of two and four.

Saxe (Saxe, 1977; Saxe & Kaplan, 1981) takes an intermediate position on the numerical significance of children's counting. According to Saxe, beginning counters acquire a list of number names they are able to repeat in a stable fashion. Initially, counting with this list does not have any numerical significance. Subsequently, there is a developmental shift in which counting takes on numerical significance and becomes a tool that children use to represent number. This shift occurs gradually and is rooted in children's developing construction and coordination of several cognitive operations which constitute the logic underlying counting.

Saxe based his position on the results of several studies. In one study (Saxe & Kaplan, 1981) two, four and six year old subjects were asked to count arrays under two conditions. In the first condition, subjects were allowed to point to objects as they counted; in the second condition they were not. Comparisons of accuracy under the two conditions indicated no significant differences between conditions in the two year old group. These subjects had many errors under both conditions. Children in the four year old group were significantly more accurate in the "gesture allowed" condition than they were when prevented from using gestures. There were no differences between conditions in the accuracy of the six year olds. Children in this group were accurate under both conditions.

A comparison between the two and four year old subjects in the study described above is crucial to Saxe's position. He argues that the two year old group's inability to improve their accuracy when allowed to point indicates their counting has not yet become a system of numerical representation. He suggests that the pointing which accompanied the two-year-old's counting was part of a naming activity. The goal of this activity was to reference names (in this case number words) to objects rather than to mediate an accurate count. In contrast, the difference found between conditions in the four-year-old group indicates that these children recognized the need for accurate correspondences and were able to use pointing gestures to facilitate their counting accuracy. In summary, Saxe and Kaplan's (1981) study suggests that the ability to use pointing to mediate counting results from a developmental shift in their conceptual understanding of counting. During this shift the goal of counting changes from the referencing of names to objects to producing a numerical representation of those objects.

In an earlier study, Saxe (1977) asked children to compare and reproduce arrays numerically. He recorded children's use of pointing and their strategies for comparing and reproducing arrays. The analysis of children's pointing identified several types of correspondences:

a) global correspondences: numbers were recited as the child made a continuous sweeping gesture across the objects.

b) many-to-one correspondences: numbers were recited as the child made discrete pointing gestures towards objects. However, the numerals, gestures, and objects were not in one-to-one correspondence.

c) accurate counting: child constructed accurate correspondences, one number for each object.

Findings indicate that three-year-old children used predominately global and many-to-one gestures. While some of the four-year-olds used accurate counting, many still used the global and many-to-one gestures. As would be expected the seven-year-olds counted accurately on most arrays.

The analysis of strategies used to compare and reproduce arrays identified two types of strategies:

a) Pre-quantitative: children did not use their counting effectively to complete the task. An example was children who counted all the objects of both arrays of a comparison task as if they were one array and then based their decision on a perceptual characteristic of the array.

b) Quantitative: children used their counting effectively to make a judgment as to the comparative numerosity of arrays or to reproduce a model array.

Findings indicate almost all of the three year old subjects used pre-quantitative strategies. Some of the four year olds used quantitative strategies, however, pre-quantitative strategies still predominated in that group. Almost all of the seven year olds used quantitative strategies.

An interrelationship was found between correspondence accuracy and strategy type. Children who used quantitative strategies had more accurate correspondences than did children who used pre-quantitative stratagies. Based on these findings Saxe suggested that both accuracy and strategy use are regulated by the same underlying cognitive development. In this view, two things occur as the child realizes that the use of counting in determining the numerosity of an array requires that number names be applied in one-to-one correspondence. One, accuracy improves since accuracy is now motivated by an understanding of the logic of the counting system. Two, the child constructs quantitative strategies to compare and reproduce number since counting is now understood as a means to extract numerical information from arrays.

Saxe (1979) proposed a model of the development of counting abilities in children which suggests that children's counting can only be used as a symbol system when it is organized by certain cognitive operational structures, specifically, successive iteration and progressive summation. In a successive iteration the child names individual objects successively, but does not relate each successive element to all of its preceding elements. In a progressive summation the child treats a collection of discrete elements as a group, referring to the group as "these" or "the blue ones", but the individual elements lose their discrete character. Each of these operations alone is insufficient for the child's counting to have quantitative significance. In order for counting to attain quantitative significance the child must be able to consider each element as an individual object and, at the same time, include that individual object within a progressive summation of all the objects in the collection.

Saxe described three phases in the developing coordination of successive iteration and progressive summation. During the first phase, children are able to perform both successive iterations and progressive summations independently, but are unable to coordinate the two operations. For example, phase one children may consider elements successively in counting, but they focus on them as individuals and ignore the collection. At other times, they may approach a collection in summary fashion with sweeping gestures and ignore the elements as individual units. The goal of counting during phase one is non-quantitative. That is, children do not attempt to determine the cardinal value of the collection. Instead, they include and exclude elements in a count as a function of variables such as the proximity of elements to one another.

During the second phase, children's counting shows clear progress toward the coordination of operations and the formation of a notational symbol system. These children are concerned with relating an iteration of individual elements to their membership in a group, and attribute a special status to the last numeral recited in an enumeration. The goal of counting during this phase is quantitative, in that children include elements in a count in order to produce a "summary" description in numerational terms of some quantitative dimension of the collection. However, this dimension may be spatial rather than cardinal. Children during this phase will frequently begin a count with the goal of representing a cardinal value but will change in midstream to represent an intuitive spatial evaluation.

Children who have attained phase three have achieved an operational coordination between successive iteration and progressive summation. The goal of counting during this phase is to organize an array of objects, including objects based on numerical considerations. This advance in turn leads children to use counting for quantitative ends when extracting, comparing, or reproducing numerical information as did the older subjects in the Saxe (1977) study.

Summary. The studies by Gelman and her associates suggest that preschool children have some understanding of the concept of number and are able to use counting to represent quantity, at least for small sets. This position is at odds with that of Piaget and suggests that Piaget may have overlooked preliminary phases in the development of counting. The study by Schaffer, et al. (1974), suggests that although young children may demonstrate the ability to apply some of the logical principles that make up a counting system, they are not facile at abstracting certain properties of numbers from their counting. Saxe (1979), has proposed a model to account for the various levels of understanding identified in preschool children. His model holds that children's counting is initially a nonnumerical naming activity which only gradually becomes a system of numerical representation. Furthermore, this developing conceptual understanding serves to motivate children's construction of strategic behaviors, such as pointing, which facilitate counting accuracy and the ability to solve number-related tasks.

Use of Strategic Behaviors to Facilitate Counting Accuracy

Sighted children create various strategies to facilitate the accuracy of their counting (Schaeffer, et al., 1974; Beckwith & Restle, 1966; Shannon, 1978). Both the physical characteristics of individual objects and their arrangement in an array are used to assign a single number name to each and every object and to partition counted objects from those still to be counted.

Schaeffer, Eggleston and Scott (1974) presented 4-and 5-year-old subjects with two sets of randomly arranged objects identical in set size and arrangement. One array was composed of homogenous objects. The other array was divided into several homogeneous subsets of elements which were heterogeneous with respect to the other subsets. When presented with these heterogeneous arrays, children counted elements by subgroups on 95% of the trials. Their performance in the heterogeneous condition was significantly better than in the homogenous condition. The children appeared to be able to use physical characteristics of objects (subgroups) to facilitate the counting of large arrays (7-14 objects).

Beckwith and Restle (1966) investigated children's ability to use the spatial arrangment of objects to facilitate counting accuracy. Children from seven to nine years of age were presented with arrays of objects differing in configurational arrangement. Objects were arranged randomly, in a circle, as a rectangle, or in a linear row. Children counted more accurately under certain conditions, accuracy progressively improved as the characteristics of the arrays were varied from random to circular to linear to rectangular. This study suggests that children perceptually group subsets to facilitate counting accuracy.

The studies summarized above (Schaeffer et al., 1974; and Beckwith & Restle, 1966) indicate that children are able to use the physical characteristics of individual objects and how they are configured in an array to facilitate counting accuracy. These studies did not, however, consider possible developmental changes involved in the ability to use ordering strategies.

Shannon (1978) investigated developmental differences in counting strategies. Children ranging from three to six years of age were asked to count arrays of objects arranged in columns and rows. Comparisons between age groups were made for both counting accuracy and the direction of counting path. The youngest children utilized what Shannon refers to as "proximal" counting strategies, e.g., they counted objects based on their proximity to other objects without using rows or columns. The group intermediate in age used a "peripheral" strategy, e.g., they counted the elements on the outside perimeter of the array before those on the inside. The oldest subjects used "linear" strategies to count up and down columns and back and forth across rows. The efficiency of these strategies differed significantly. Children who used "Linear" strategies were more accurate than those who used "peripheral" strategies who in turn were more accurate than those who used "proximal" strategies. Shannon concluded that children adopt spatial strategies designed to bring order to counting tasks, but that the type of strategy used depends on the level of processing capabilities attained.

The Schaeffer et al. (1974), Beckwith and Restle (1966) and Shannon (1978) studies all indicate that sighted children in the older age groups use the physical characteristics and arrangment of objects in an array to impose an organization on the array. Shannon's study indicates that very young children do not utilize the physical characteristics of the array. Instead, objects are counted based on spatial proximity, resulting in relatively more counting errors. Shannon attributed the development of progressively more efficient strategies to advances in children's proccessing capabilities. Another mechanism which might underlie the development of counting strategies may be the changes which occur in children's conceptual understanding of counting (Saxe, 1977). That is, as children begin to use counting as a means of producing numerical representations of objects they recognize the necessity for constructing accurate correspondences. This recognition then motivates children to create organizational strategies to facilitate counting accuracy.

This section has described the strategic behaviors used by sighted children to assure counting accuracy and has suggested a possible relationship between the construction of strategies and children's conceptual understanding of counting. One of the goals of the present research is to further investigate the nature of this relationship. In order to investigate this relationship it is necessary to have some means of assessing children's conceptual understanding of counting. The following section describes how researchers have used children's counting errors to measure the level of this conceptual understanding.

Counting Errors as Indicators of Conceptual Development

Several researchers have analyzed children's counting errors as a basis to understand the cognitive operations or principles underlying young children's counting activities. Gelman and Gallistel (1978) used an error analysis to support the position that young children understand the logical principles that underlie counting, but have difficulty with the perceptual-motor skills necessary to implement those principles. According to their model, several logical principles constitute the basis of a counting system. These principles were discussed earlier in this review and include the stable order, one-one, cardinal, abstraction and order irrelevance principles. Gelman and Gallistel (1978) found that even subjects as young as two recognized that any collection of entities could be counted and that the order in which items were counted was irrelevant to the accuracy of the count. They interpreted this finding as evidence that their subjects understood both the abstraction and order irrelevance principles, although they had difficulty with the stable order, one-one and cardinal principles. Stable order errors were rare and usually involved the repetition of a tag during a count. Errors involving the one-to-one principle were most frequent, and could be divided into two general categories of partitioning and coordination errors. Gelman and Gallistel identified four specific error types within each of these categories.

Partitioning errors:

double count - double counting an item consecutively in the middle of an array

recount - child returns to recount item already counted

omission - omission of one or more items in the middle of an array

stop too soon - child fails to count two or more of the final items in arrays

Coordination errors:

beginning - child missed or double counted item at the beginning of a sequence

end - child missed or double counted an item at the end of a sequence

overrun - child stated number words after having stopped pointing or countinued around a nonlinear array after counting each item once

asynchrony - pointing gets out of step with tagging

Among partitioning errors they found a high rate of double count and omission errors and relatively few recount and stop too soon errors. In the coordination category they found a high rate of beginning and end errors, but relatively few overrun and asynchrony errors. Gelman and Gallistel suggested that the relatively high frequency of double count, omission, beginning and end errors involve slips in moving from item to item, which result in missing an item or tagging it twice. They argued that this finding is evidence that their subjects failed to honor the one-one principle because of a lack of skill (perceptual-motor) rather than a lack of understanding of the underlying concept or rule. Analysis of cardinality errors indicated that many of their subjects were able to give accurate cardinal responses to small sets but had difficulty with larger sets. Gelman and Gallistel attributed this difficulty with larger sets to subjects' uncertainty related to difficulties they have constructing one-to-one correspondences. This position is called into question by Schaeffer et al.'s (1974), finding that even when children are able to count arrays accurately (their four year old subjects counted arrays accurately on 71% of their trials), they still have difficulty abstracting cardinal values (none of the their four year olds gave accurate cardinal responses). According to Gelman and Gallistel, even young children understand the logical principles that are the basis for counting. They merely lack the perceptual-motor skills necessary to implement their understanding.

Wilkenson (1984) provided support for the existence of several of Gelman's counting principles, which he referred to as "modular components". He investigated the tagging, partitioning and stopping components, and described children's understanding of these components as "partial knowledge" of a "variable" nature. That is, the components of children's counting are separate units or "modular components" of knowledge which must be linked together into executable algorithms. Components are retrieved from memory separately and merged as they are used. Inaccurate or "variable" performance occurs when this process of integration is undependable. According to Wilkenson, performance failures are the result of misallignment of the components, bad timing or forgetting.

In order to isolate the influence of a component on counting accuracy, Wilkenson compared children's performance on a task requiring the application of a specified set of components with their performance on another task requiring the same set of components plus an additional component.

Wilkenson hypothesized that adding a component to the task would increase the probability of errors associated with this component. He further suggested that confirmation of this hypothesis would support the position that the components identified are independent principles. Wilkenson scored his subjects' errors according to the following schema:

double - a previously used tag is repeated on a second item, or an item other than the first or last is given two different tags

skip - a tag in the number sequence is omitted or an item other than the first or last is omitted

stop early - reciting or tagging ends before the correct last item

stop late - reciting or tagging ends after going past the correct last item

other - starting errors, unspecified middle errors, repeating tags at the end after having stopped pointing, composite errors

Wilkenson's analysis indicated that adding: a) the partitioning component to a task requiring tagging alone resulted in more doubling errors, which almost always involved tagging a single item with two names; b) increasing the difficulty of stopping resulted in more stopping errors, with stops late occurring more often than stops early, implying that children were better able to identify items as not counted rather than counted already;

c) adding the tagging component resulted in more skipping errors.

Because Wilkenson obtained errors which he had hypothesized would occur by adding the specified components, Wilkenson argued that his findings were support for the existence of his "modular components" as well as Gelman and Gallistel's position that young children's errors result from execution or implementation difficulties of a perceptual-motor nature.

Both the Gelman and Gallistel (1978) and Wilkenson (1984) studies analyzed children's counting errors to support the position that these errors reflect the difficulty children have in implementing their knowledge of the principles underlying counting. However, when Saxe (1977) asked his subjects to count, compare and reproduce arrays he identified the existence of several kinds of correspondence errors different from those described by either Gelman and Gallistel or Wilkenson. Saxe referred to the correspondences he identified as "global" and "many to one". Both correspondences involve the recitation of number names without correspondences being established between numerals, gestures and individual objects. The errors which accompany these forms of correspondence are difficult to consider as omissions or double counts. For example, if a child places its hand on one object in an array of five and recites "one, two, three" it seems unlikely that the child missed the remaining two objects and was slow to move its hand away from the first object. It seems more reasonable to assume that the child does not yet understand the need for accurate correspondences and is using counting words for some other purpose, such as the naming activity suggested by Saxe. The many-to-one errors which Saxe describes are more likely the result of a lack of development on a "conceptual" level rather than on an implementation or "perceptual-motor" level as those described by Gelman and Gallistel or Wilkenson.

In summary, researchers have used children's counting errors to make inferences concerning their understanding of counting. These errors can be attributed to two sources: errors that are the result of a lack of development on a "conceptual" level and errors that result from a lack of development on a "perceptual-motor" level.

Tactile Perception in the Blind

The counting strategies discussed in the previous sections (pointing and utilizing the physical characteristics or configurational arrangements of objects) involved the use of visual-motor skills. Children deprived of visual input due to either physical impairment or experimental manipulations must create counting strategies which depend on input from other perceptual-motor systems. The studies described in this section suggested that blind children would create tactile strategic behaviors to facilitate counting accuracy.

Studies of blind children indicate they begin to substitute tactile for visual behaviors during infancy. Fraiberg (1977) found that blind infants tend to use their hands instead of facial expressions to communicate with their mothers. Whereas sighted infants maintain contact with their mothers through visual signs and are reinforced through visual rewards (a returning smile), blind infants are unable to detect these rewards and therefore do not learn to initiate interactions by smiling. Instead, blind infants communicate wants, intentions and needs through hand gestures. With the assistance of a sensitive mother, hand gestures in the blind infant become an effective mode of communicating with the social environment.

In later life, blind individuals organize hand gestures and tactile motor movements into well-articulated and finely-differentiated tactile-motor strategies (Davidson, 1972; Davidson and Whitson, 1974; Davidson, Dunn, Wiles-Kettenmann and Appelle, 1981). Davidson (1972) assessed the ability of blind relative to blindfolded-sighted, adults to determine whether the edge of an object was concave, convex or straight. Both the response accuracy and types of strategies used were analyzed. When the performance of blind adults was compared to that of blindfolded-sighted adults, Davidson found that the blind subjects were both more accurate and used more efficient strategies more frequently than did the blindfolded-sighted subjects. In a shape matching study, Davidson et al. (1974) presented blind and blindfolded sighted adults with the same objects as those used in the identification study. This time, however, he asked the subjects to match the curve on the edge of the stimulus object to the edge of several possible matching objects. As in the first study, Davidson found that blind subjects outperformed blindfolded-sighted subjects both in terms of accuracy of response and efficiency of strategy.

Having established that blind adults create tactile strategies to accomplish cognitive tasks, Davidson et al. (1981) decided to investigate whether blind children also create similiar strategies and to determine the relationship between these strategies and conceptual development. He presented blind children (ages 9 to 16) and both blindfolded and unblindfolded-sighted children (ages 5 to 12) with Piaget's conservation of mass task. Several types of behaviors were recorded, e.g., children's conservation judgments, the number and type of search strategies applied to each individual clay figure and the number of judgments in which the child felt both lumps of clay simultaneously. Davidson's previous research (1974) had indicated that simultaneous exploration of both shapes is an effective strategy for comparing multiple stimulus attributes and would be a particularly useful source of information for conservation judgments.

The results of Davidson's study indicated that blind subjects lagged an average of 3.5 years behind both sighted groups in the attainment of conservation. With respect to strategies, blind children, regardless of their conservation status, actively explored the stimuli more often than either of the sighted groups. Davidson observed, however, that many of the blind subjects' strategies were not useful in making conservation judgments. An analysis of the percent of judgments in which subjects simultaneously searched the two figures indicated a significant difference between the blind conservers and blind non-conservers. Blind conservers simultaneously explored both objects significantly more frequently than did the blind non-conservers.

Davidson's findings indicate that congenitally blind children create tactile motor strategies which facilitate their judgments and that the development of these strategies depends on the child's level of conceptual development. It was therefore expected that blind children in the present study would create tactile strategic behaviors to facilitate the accuracy of their counting and that the type of tactile strategy used would be closely tied to the child's conceptual understanding of counting.

Qualitative Differences between Visual and Tactile Perception

While both visual-motor and tactile-motor strategies can be used to extract information from physical reality, each sensory system has distinct characteristics which influence the quality of the information obtained.

Researchers have investigated differences in the characteristics of visual and tactile perception and the relationship between these differences and conceptual development. Gibson (1962) suggested that each sense has its special sensitivities to the properties of a surface. While the eyes take in an entire object from end to end with a single glance, the hands can explore only a limited amount of the object's area. In other words, visual perception is based on "simultaneous" registering of the whole contour, while tactile perception is based on "successive" registrations.

Piaget and Inhelder (1964) investigated the relationship between the simultaneous versus successive characteristics of visual and tactile perception and conceptual development. They presented children with identical materials under two conditions. In one condition materials were hidden from view by screens and subjects were asked to classify or seriate the materials tactilely. In the second condition the screens were removed and subjects were allowed to use sight to classify or seriate the same materials. Certain cognitive activities appeared to be facilitated while others were delayed under each condition. Piaget and Inhelder suggested that these differences in performance were due to qualitative differences between tactile and visual perception, particularly the "successive" nature of tactile perception and the "simultaneous" nature of visual perception. Their findings suggest that the application of conceptual abilities, in contexts which require the use of different perceptual-motor systems, will be influenced by specific characteristics of the particular sensory system employed.

The literature on the use of tactile perception in blind children suggests that blind subjects would utilize tactile strategic behaviors as aids when counting. In addition, Gibson's views on perception and the findings of Piaget and Inhelder (1964) suggest that the use of visual-motor versus tactile-motor strategic behaviors during partitioning and coordination processes would lead to qualitative differences in the counting behaviors of blind and sighted children.

A Comparative and Developmental Analysis of Children's Counting

The present research involved both a developmental and a comparative analysis of children's counting. The goals of the developmental analysis were: first, to identify and describe differences in the types of counting strategies used by blind children at different ages and levels of counting proficiency; second, to determine if there is evidence of conceptual errors in children's counting; and third, to determine if there is a relationship between conceptual errors and the development of strategic behaviors. The comparative analysis consisted of comparisons between the error profiles of blind and sighted subjects. The goals of the comparative analysis were: first, to establish whether there are differences in conceptual and/or implementation errors between blind and sighted subjects; and second, to use the findings on differences in implementation errors between blind and sighted subjects to test the position that many of children's counting error are related to difficulty they have mastering perceptual-motor skills.

For the purposes of the present study, I constructed several counting tasks that varied on two dimensions. The first dimension was object mobility. In half the arrays, objects were loose and could be moved around during the counting operation. In the other half, objects were fixed to boards and could not be moved. The second dimension was spatial configuration. Arrays were presented in four configurations: linear, circular, homogenous random and heterogeneous random. A pilot study indicated that these task variations elicited a range of strategic behaviors and lead to a variety of different counting errors. These tasks were presented to blind, sighted, and blindfolded-sighted children of varying ages.

The following is a description of the rationale for the four sets of hypotheses tested in the present study. The first set of hypotheses concerned blind and blindfolded-sighted children's tactile strategic behaviors. Research described above on visual-motor counting strategies in sighted children and the development of strategies in blind children suggested that blind children would develop tactile-motor counting strategies to accomplish the same functions as visual-motor strategies accomplish in sighted children. Observations made in a pilot study revealed that blind adults employ a system integrating discrete, interconnected, tactile-strategic behaviors to facilitate their counting accuracy. Blind children also counted using tactile-motor behaviors, but their behaviors were much less sophisticated and produced many errors. The present study sought to identify and describe the fully-developed system of strategic behaviors used by accurate counters, suggest a plausible sequence in the development of these strategies, and test the adequacy of the proposed sequence. The following hypotheses were those used to test that sequence:

Hypothesis 1:

Older subjects would use higher levels of each of the strategies than would younger subjects.

Hypothesis 2:

Subjects who are more accurate counters would use higher levels of each of the strategies than would less accurate counters.

Blindfolded-sighted subjects were tested to further substantiate the developmental sequence of tactile-strategic behaviors found in blind subjects. They were presented with the complete set of arrays on several consecutive days. It was predicted that blindfolded-sighted subjects would progress through the same sequence of levels as they develop more efficient strategies over repeated trials. In order to test this prediction the following hypothesis was made:

Hypothesis 3:

> The level of strategic behavior used
> would increase on consecutive days for the
> blindfolded-sighted subjects.

The second set of hypotheses were constructed to test Saxe's suggestion that children's conceptual understanding of counting changes during development. The literature review described two categories of errors. One group indicated a lack of understanding of the need for accurate correspondences (conceptual errors), while the other indicated adequate conceptual development but difficulty mastering perceptual-motor skills (implementation errors). If Saxe's shift in conceptual knowledge in fact occurs it should be reflected in the types of errors made by both blind and sighted children. Specifically,

Hypothesis 4:

> Many-to-one errors (many number names stated
> while touching or holding one object) would

make up a larger percentage of the total number of errors of younger, less accurate counters than older, more accurate counters.

Hypothesis 5:

Implementation errors (counting the same object twice, omitting an object) would make up a smaller percentage of the total number of errors of younger, less accurate counters than older, more accurate counters.

The third set of hypotheses tested the argument that the development of strategic behavior is motivated by children's conceptual understanding of counting. That is, young children do not develop strategies to assure the accuracy of their counting because counting is initially a non-numerical naming activity. As children become aware that counting can be used to represent quantities, they begin to recognize the importance of accurate correspondences. This recognition leads them to create strategies to ensure the accuracy of those correspondences. In order to test this model, comparisons are made to determine if the development of efficient strategic behaviors is related to conceptual development, as reflected in the types of errors (conceptual vs. implementation) children make. It was hypothesized that:

Hypothesis 6:

Children who use the lowest level strategies would have a higher percentage of many-to-one errors (conceptual errors) than would children who use higher level strategies.

Hypothesis 7:

Children who use the lowest level strategies would have a lower percentage of implementation errors than would children who use higher level strategies.

The fourth set of hypotheses concerned similiarities and differences between the counting activities of blind and sighted subjects. A comparison of counting behaviors of subjects who use different perceptual-motor systems enables us to isolate the influence of perceptual-motor skills from that of conceptual abilities, two factors that regularly co-vary in studies using only sighted children. Piaget and Inhelder (1964) suggested that the implementation of conceptual knowledge is affected by characteristics of the perceptual-motor system with which it is implemented. This suggested that the use of different preceptual-motor systems by blind and sighted children would influence their counting behaviors (the specific types of perceptual-motor errors they make). Confirmation of this prediction would support the view that errors categorized as implementation errors have a perceptual-motor basis as well as provide data on the nature of differences in the counting behaviors of blind and sighted children. In order to investigate this position, comparisons of two types were made: 1) the specific types of errors made by blind, sighted, and blindfolded-sighted subjects and 2) counting performance under different task conditions. Several specific hypotheses were tested.

No differences were expected between blind and sighted subjects for certain types of errors. The use of stably ordered lists of words and the tagging component are both highly verbal activities which rely little on visual-motor or tactile-motor experience. It was therefore hypothesized that :

Hypothesis 8:

> There would be no significant differences
> between the blind and sighted subjects
> on either order violation (stating a numeral
> out of order) or tag duplication (repeating
> a numeral more than once during a count)
> errors.

Differences were expected to occur between blind and sighted subjects for other types of errors. Blind children's tactile strategies provide inputs successively and temporally, while sighted children's visual strategies provide simultaneous inputs. It was expected that this difference would lead to certain implementation errors appearing more frequently for blind subjects. More specifically, double count errors (counting the same object more than once consecutively) and internal omission errors (omitting an object when those around it have been counted) result from the failure to partition and select objects successively. On the other hand, recount errors (returning to recount an object after the other objects in an array have already been counted) and peripheral omission errors (omission of an object at either the beginning or end of a counting path) result from the failure to keep track of whether entire areas of the array have or have not been counted. It was predicted that:

Hypothesis 9:

Recount and peripheral omission errors would make up a larger percentage of blind than sighted subject's errors.

Hypothesis 10:

Double count and internal omission errors would make up a larger percentage of sighted than blind subject's errors.

The errors made by blindfolded-sighted subjects were used to further investigate the position that implementation errors are the result of difficulty mastering perceptual-motor skills. Prior to participating in the present research, blindfolded-sighted subjects had experience with visual-motor strategies but little, if any, experience with tactile-motor strategies designed to facilitate counting accuracy. For the purpose of the present research, these subjects were required to use tactile-motor strategies to count the arrays. It was predicted that, if the types of implementation errors children make are in fact the result of difficulties they have mastering perceptual-motor skills, then:

Hypothesis 11:

> Errors made by blindfolded-sighted subjects
> would be more similiar to errors made by
> blind subjects than sighted subjects

The final hypotheses tested in this study concerned the effects of various task conditions on blind and sighted subjects. When presented with loose object arrays, subjects could move objects to another section of the tray. Putting a distance between the already counted objects and those still to be counted aids children in the partitioning process. It was therefore predicted that:

Hypothesis 12:

> Blind and sighted subjects would have
> a lower absolute number of errors on the
> loose than on the fixed arrays.

The simultaneous nature of visual perception allows sighted children to monitor the spatial location of all objects in an array at the same time, thus facilitating the accuracy of their counting on fixed arrays. The successive character of tactile perception does not allow blind children this advantage. It was therefore predicted that:

Hypothesis 13:

> Differences between the accuracy scores
> on fixed and loose arrays would be
> greater for blind than sighted subjects.

CHAPTER II

Method

Design

In order to obtain systematic observations of the counting behavior of blind, blindfolded-sighted and sighted children at different developmental levels, children at various age levels from each population group were observed under two conditions. In one condition, objects were presented loose in a flat tray. In the other condition, objects were glued to sheets of plywood. Within each condition, children were presented with arrays arranged in four different configurations, these included linear, circular, homogenous random and heterogeneous random.

Subject Population Selection

Counting behaviors in blind children were initially observed in a pilot study connected with the present research. In the pilot study, congenitally blind children and adults between the ages of 5 and 26 were presented with a variety of counting tasks. Results indicated that blind children as old as 14 years of age had difficulty counting the arrays accurately. This is considerably older than the age, at which, according to previous research, sighted children would master these tasks. Since the goal of comparing blind and sighted subjects' counting behaviors was to identify qualitative differences in their counting at comparable points during development, a decision was made to match subjects based on level of counting proficiency.

Blind subjects. In order to include subjects who would exhibit a wide range in counting strategies and accuracy, 24 congenitally blind children between the age of (3-6) and (13-11), with a mean age of (8-5) were used as subjects in the present research. Each child's records were reviewed to ensure that all subjects were blind at birth, and had no additional physical or psychological disabilities.

Sighted subjects. Studies of sighted children's counting have indicated that children as young as five should have little trouble successfully completing the tasks used in the present study. In order to include subjects who would exhibit a range in number of errors similiar to that of the blind subjects, 26 sighted children between the age of (3-0) and (4-9), with a mean age of (3-9) were used as subjects in the present research.

Blindfolded-sighted subjects. Piloting the use of a blindfolding screen indicated that levels of counting proficiency in the blind and sighted groups could be matched by including blindfolded-sighted children between the ages of four and six. Therefore, a number of children were interviewed at each of three age levels: 15 four year olds, (4-0) to (4-11) mean age (4-4); 15 five year olds, (5-1) to (5-10), mean age (5-5); 16 six year olds, (6-0) to (6-9) mean age (6-4). The mean age for the entire group was (5-4).

Task Selection

In the pilot study, a wide variety of tasks were presented to blind subjects. Observations of their performance on these tasks led to the selection of eight tasks which appeared to be representative of everyday counting situations. The tasks elicited a wide range of counting behaviors across population groups and differed on two dimensions: object mobility and configurational arrangement.

Object mobility. In half of the tasks, objects were fixed to sheets of plywood preventing subjects from moving them during the counting process. In the remaining tasks, objects were presented loose in a shallow box, allowing subjects to move them about during a count. The pilot study revealed that when given the opportunity to relocate objects subjects used a variety of organizational and partitioning strategies in addition to the strategies used on fixed arrays.

Configurational arrangement. Both the fixed and loose arrays were presented in four different configurational arrangements: linear, circular, homogenous random and heterogeneous random (an identical random array in which objects are divided into three heterogeneous subgroups).

Figure 1 depicts each of the four configurational arrangements. The pilot study revealed that varing the configuration of objects places different demands on subjects. For example: (1) random arrangements provide less perceptual support for organizing the direction of a count than either linear or circular arrays; (2) circular and random arrangements require subjects to produce a reference point for the organization of a count in contrast to a linear array, which provides subjects with both a start and a finish point; (3) arranging objects into subgroups allows the use of certain partitioning strategies not available in the non-subgrouped arrangements.

Blindfold Construction

Blindfolding young children turned out to be a difficult procedure. During piloting, various over-the-eyes blindfolds were constructed and several 4-to-6 year-old children were asked to wear these blindfolds while counting sample arrays. Children found the blindfolds disorienting, particularly when asked to perform tasks they ordinarily have little difficulty completing. Most children either refused to count or peeked over or under the blindfolds. After considerable attempts to construct an adequate over-the-eyes blindfold, it was decided to use a screening device that obstructed children's view of the arrays. This device consisted of a sheet of cardboard mounted on blocks of wood. The sheet was placed in front of children, blocking their view of the arrays, which were placed behind the screen. A cutout was made below eye level through which children could put their arms; this enabled them to count the arrays without their hands being restricted by the physical apparatus.

While blindfolded-sighted children were asked to count all the arrays on each of four consecutive days, all but a few of the subjects refused to participate on the third day. As a result, blindfolded-sighted subjects counted the arrays on only two consecutive days.

Materials

Fixed arrays.

Linear - 1 1/8" x 1 1/8" smooth blocks were attached to a 7" x 14" sheet of 1/4" plywood in a linear row.

Circle - Blocks identical to those specified above were attached to a similiar sheet of plywood in a circular arrangement.

Homogenous Random - Identical blocks were attached to a similiar sheet of plywood in a random arrangement.

Heterogeneous Random - Three groups of wooden blocks 1-1/8" cubes, 1/2" cubes, and 3/4" pyramid shapes were arranged in spatial subgroups in a random arrangement identical to the homogeneous random arrays.

Loose arrays. Objects identical to those used in the fixed arrays were presented loose in a 12" x 14" tray in each of the four arrangements used for the fixed arrays.

Blindfold screen. A 17" x 22" sheet of cardboard was covered with colored contact paper. A 4" x 14" rectangular hole was cut out of the center at the bottom of this screen. A wooden brace attached to both ends of this sheet supported it on the table.

Procedure

Before being presented with the tasks, each subject was asked to count from one to ten by rote. Any subject who could not use the conventional number-word sequence was excluded from the study. None of the blind or blindfolded-sighted children and only two of the three-year-old sighted children originally interviewed had to be excluded. After the rote counting assessment had been completed, subjects were presented with tasks one at a time; the presentation order of all tasks was counterbalanced. The presentation order of object mobility was varied so that half the subjects in each group received the fixed arrays first, while the other half received the loose arrays first. In addition, the order of configurational arrangements within each set of fixed and loose arrays was randomized. There were three trials of each task condition, one at each of three set sizes (seven, eight, and nine objects). Because set size was not a variable, the order of set size presentation was not varied. During each task the child was presented with an array of objects and was asked to "count these blocks and tell me how many there are". Children who failed to state a cardinal value at the end of the count were asked, "How many are there all together"? Subjects' performance on all tasks was videotaped. Videotaping was necessary in order to allow for the careful analysis of strategic behaviors and the exact location of errors. Videotapes were later coded using schemas described in the results chapters.

Figure 1

fixed and loose linear

fixed and loose circular

fixed and loose homogeneous random

fixed and loose heterogeneous random

Object Arrangements for Both Fixed and Loose Arrays

CHAPTER III

Analysis of Tactile-Motor Strategies

The purpose of this chapter is to describe the development of counting strategies in blind children. On the basis of an inspection of videotaped records of blind children's counting behaviors, I distinguished three strategic dimensions: preliminary scanning, count organizing and partitioning. In the first section of this chapter, I will describe the nature of these dimensions and illustrate their utility for documenting how accurate counters approach the task of producing numerical representations of arrays. In the second section, I will present a preliminary analysis of a sequence of steps in the development of these dimensions, and use selected videotaped records to illustrate this sequence. In the final section, I will present data which support the proposed sequence.

Dimensions of Blind Children's Counting Behaviors

This section describes the three dimensions of strategic behaviors observed in blind children's counting. "Scanning strategies" are behaviors which occur before the child begins to count the array. The purpose of these strategies is to explore the array and determine if there are any physical characteristics, such as its configuration, which can be used to organize the counting process. "Count organizing strategies" refer to the child's use of a particular characteristic of the array as a means of organizing the counting operation. These strategies consider objects as members of a group, rather than as individual elements. "Partitioning strategies" are behaviors which deal with objects as individual elements rather then as members of a group. These strategies are used to select objects one at a time while maintaining an ongoing separation between objects already counted and those still to be counted.

When used by accurate counters, the three dimensions described above are interdependent. A scanning strategy is used to determine the size of the array and the existence of any distinctive characteristics which can be used to organize the counting process. Based on information derived from the scanning strategy, children begin the counting process. As they count the objects, they use a count organizing strategy which follows a salient characteristic of the array, such as its circularity. As they move around the circle they use some type of partitioning strategy which enables them to select individual objects and to separate objects already counted from those still to be counted.

Some Illustrations of the Three Dimensions

Following are examples of the three dimensions of strategic behaviors used by accurate counters. The examples demonstrate how these dimensions are applied to counting both fixed and loose linear arrays of seven objects. Both types of arrays are included to illustrate the different behaviors used under the two conditions.

Fixed array example. The following is a description of the behaviors of a child presented with a sheet of plywood with seven blocks glued to its surface in a linear row.

> Emi (13-2) stretched out his right hand until he touched the first object. Then he placed his left hand next to his right hand and moved both hands across the top of each object in the array, following the array in each direction until he had passed each of the endpoints.
>
> After exploring the array in each direction, Emi placed his left hand on the leftmost object and stated the numeral "one". At this point he kept his left hand on that object and placed his right hand on the top of his left hand. He then moved several fingers of his right hand toward the right until he came in contact with the next closest object. As he touched this object, he stated the numeral "two" and moved several fingers of his left hand across the top of that object. He now had his left hand on objects "one" and "two". At this point, he placed his right hand on top of his left hand and began moving several fingers of his right hand toward the right until he came in contact with the next closest object. This procedure continued until he had counted all

the objects in the array at which time he said "seven, there are seven blocks".

The behaviors just described can be analyzed in terms of the three strategic dimensions presented earlier. The first step the child made was to run his hands across the top of each object in the array. I refer to this behavior as a "preliminary scanning strategy" which occurs prior to the construction of the first one-to-one correspondence. Preliminary scanning strategies provide information about the physical characteristics of individual objects, such as their shape, and the arrangement and extension of objects in the array. This information is then available for planning the order in which objects will be counted.

After scanning the array the child begins to construct one-to-one correspondences. The child's behaviors during this process can be divided into two strategic dimensions: "count organizing" and "partitioning". Using the array's linear arrangement to organize the counting procedure is referred to as a "count organizing" strategy. In the example cited above, the child began the counting process with the leftmost object. After counting this object, he counted objects along the row from left to right, thus using the array's linear arrangement to facilitate accuracy.

The child's use of his hands to select one object at a time and to separate objects already counted from those still to be counted is referred to as a "partitioning" strategy. As the child moved along the row, he grouped objects already counted with one hand, while reaching out with the other hand toward objects still to be counted. The search for the next object was a carefully controlled movement. The child gradually increased the area of the search along the row until the next object was located.

<u>Loose array example.</u> The following is a description of the behaviors of a child presented with a wooden tray containing seven loose blocks arranged in a linear row.

> Cal (12-4) reached out his right hand until he touched the first object. He picked the object up for a second and then placed it back on the tray. Next, he placed his left hand on the surface of the tray and moved it along the surface of the tray until he encountered the leftmost border of the tray, He then placed his entire forearm on the surface of the tray, gradually moving it across the surface of the tray in a sweeping motion toward the right border. In this manner, he moved all the objects to the right side of the tray.
>
> Having completed this sweeping action, Cal picked up one of the blocks with his right hand and stated the numeral "one". Reaching out with his left hand for the leftmost border of the tray, he placed the block along this edge and then

returned his right hand to the right side where he selected the next block and stated the numeral "two". This procedure continued until he had counted all the objects in the collection, stating the numeral "seven" as he moved the last block. At this point he placed his right hand in the middle of the tray and with a sweeping motion ran his hand across the right half of the tray. Finally, he said "there are seven blocks".

The series of behaviors outlined above can also be analyzed in terms of the three strategic dimensions described as serving certain functions in the fixed array example.

As a "preliminary scanning strategy", the child reached out his hand until he touched the first object. He then lifted that object and placed it back on the tray surface. This behavior occurred prior to the construction of the first one-to-one correspondence.

As explained earlier, the purpose of scanning strategies is to identify characteristics of objects in an array which allow for the use of further strategies to facilitate the counting procedure. These characteristics are identified more readily on loose, as opposed to fixed arrays. Children need pick up only one object of a loose array to realize that objects in the array can be relocated. When objects can be relocated, children can use a number of count organizing and partitioning strategies. In contrast, it is necessary for children to touch all objects in a fixed array to determine which, if any, organizational and partitioning strategies can be applied to the array.

In the example given above, the child began to count after he had scanned the array. The counting behaviors he used can also be categorized into the two strategic dimensions identified in the fixed array example. As noted previously, these dimensions differ in function and are referred to as "count organizing" and "partitioning" strategies. In the present example, the child swept all the objects to one side of the array, and then proceeded to count the objects, moving each object to the leftmost section of the tray after counting it. When the child had finished counting, he ran his fingers along the surface of the tray to make sure he had not missed any additional objects. Relocating the objects in the array served to organize the entire group of objects, it is therefore referred to as a "count organizing strategy".

As the child relocated the objects he picked up one block at a time, stated a single numeral and then placed that object down on the leftmost section of the tray with the other objects he had already counted. This strategy differs from the count organizing strategy in that it deals with blocks as individual units as opposed to the count organizing strategy which dealt with the collection as a whole. It is possible for a child to move all the blocks at one time when counting which would be an effective organizing strategy but ineffective partitioning strategy. This procedure of constructing individual correspondences is referred to as a "partitioning" strategy.

Summary. The description of the counting behaviors of accurate counters identified three dimensions of strategic behaviors, each of which serves a particular function. Scanning strategies occur prior to the construction of the first correspondence. The purpose of scanning strategies is to provide information about the physical characteristics of individual blocks and of the array as a whole. This information can then be used to construct correspondences.

Two types of strategic behaviors are involved in constructing correspondences, e.g. count organizing and partitioning strategies. Count organizing strategies deal with objects as members of a group; they function to organize the counting process using perceptual characteristic of the total array. Partitioning strategies deal with objects on an individual basis, and appear in the context of count organizing strategies. For example, if a child is counting along a row (count organizing strategy), he will use some form of movable partitioning system to select objects one at a time and to partition objects already counted from those still to be counted.

Examples were used to illustrate how the three strategic dimensions --scanning, count organizing and partitioning strategies-- are interrelated, working together as a well integrated system. The accurate counter uses this system of strategies to construct accurate numerical representations of sets of objects.

Development of Tactile-Motor Strategies

The efficient organization of the three differentiated strategy types described above was observed in accurate counters. Observations of the counting of less accurate counters revealed behaviors which represent earlier steps in the development of the differentiated or articulated endpoint strategies used by accurate counters. The purpose of the present section is to describe these developmental levels for each strategic dimension. The use of the term level in this case refers to advances in terms of the amount of information provided by a particular strategy. These advances do not necessarily reflect structural changes often considered to underly advances between qualitative different levels of cognition.

Preliminary Scanning Strategies

An inspection of children's protocols indicated three levels in the development of preliminary scanning strategies. These levels differ from one another in terms of the organization and extent of the child's search behavior. Table 1 contains a summary description of these levels for both the fixed and loose array tasks. A more detailed description of these behaviors is presented below.

<u>Fixed Arrays.</u> At level one, children reached out to place their hands on the array. The moment they touched the first object they began to count. This behavior served only to locate the array and provided no additional information regarding the extent of the array or the shape or configuration of objects.

At level two, children touched the first object and then explored the immediate area around that object. While this behavior provides some information concerning the shapes of a few of the objects in the collection, the information gained is limited. These children did not proceed with an organized, exhaustive search of the array. They could not determine the endpoints of the array in either direction nor could they determine array extension or any of its distinctive characteristics, such as its configuration or degree of homogeneity.

At the third level, children touched the first object and then proceeded to touch each object in the array in an organized, systematic manner. This search provided the information about both the individual objects and the array necessary for planning and organizing the count.

<u>Loose Arrays.</u> Before considering the levels of scanning used on loose arrays, it is necessary to point out an important aspect of the coding procedure. When presented with loose arrays, children had two alternatives. One

alternative was to treat the objects as if they were fixed. Children who chose this alternative employed one of the strategies previously described in relation to fixed arrays. The second alternative was to relocate objects during the count. As children touched the objects in a loose array, the block or blocks they touched moved easily. However, it was impossible for the experimenter to determine from this movement alone whether or not children actually recognized the possibility of relocating objects during the count. In order to assign a level to scanning behaviors, it was necessary to consider whether or not the child went on to "organize" their count by relocating objects. When a child did use a relocation strategy, it was concluded that they had derived the information necessary to organize the count sequence from scanning the array, and their scanning behavior was coded as a level three strategy. If a child did not use a relocation organizing strategy, their behavior was coded as a level one strategy.

Because children either moved or did not move objects during the count, no scanning behaviors involving the relocation of loose objects were coded as level two scanning strategies.

Count Organizing Strategies

An inspection of children's protocols also suggested a three level schema for describing the development of count organizing strategies. Count organizing refers to the sequence in which the objects in an array are counted. Children's counting behaviors were assigned to a specific level based on how efficiently they utilized the characteristics of an array to organize the count sequence. Table 2 contains a summary description of these levels for both the fixed and loose array tasks. A more detailed description of these levels is presented below.

Fixed Arrays. At level one, children did not select objects by moving along the row or circle. These children typically counted an object on one side of the circle, then another from the opposite side, and so on. This approach represents a failure to utilize array characteristics to organize the counting process.

At level two, children selected objects by moving along the row, but did not use a reference point to keep track of where they had begun the count. While this approach is more advanced than level one, it still leads to errors such as recounting objects.

At level three, children counted the first object and then placed the finger of one hand on that object, utilizing it as a reference for the starting point of the count. They then proceeded to count the remaining objects following the organizing characteristics of the array (i.e., circle, row). This approach made efficient use of the particular characteristics of the array as a means of organizing the objects to assist in the selection and partitioning process.

<u>Loose Arrays.</u> As with the preliminary scanning strategies, children had two alternatives. They could deal with objects in a loose array as fixed objects and utilize one of the organizing strategies described in relation to fixed arrays, or they could relocate objects during the count. Three levels of count organizing strategies were observed on loose arrays.

At level one, children did not move loose objects during the construction of correspondences nor did they use one of the more advanced fixed-array strategies.

Children were assigned to level two on loose arrays if they did not move loose objects but used a strategy previously described as level two for fixed arrays. There were no transitional steps between relocating and not relocating objects that could be assigned to level two.

A child at level three picked up objects and moved them to a separate section of the tray after counting them, thus utilizing their mobility to organize the count.

Partitioning Strategies

An inspection of children's protocols also revealed three developmental levels in children's partitioning strategies. These levels differ in the degree to which they were observed to facilitate 1) the selection of a single object and 2) the partitioning of objects into objects already counted and those still to be counted. Table 3 contains a summary description of these levels for both the fixed and loose array tasks. Below is a more detailed description of these levels.

Fixed Arrays. At level one, children did not use any strategy to assist in selecting individual objects in the counting process.

At level two, children placed their hands on single objects while reciting single number names, but did not utilize any type of "movable partitioning system". (A "movable partitioning system" involves the use of one or both hands in a fashion which enables the child to create an ongoing partitioning of objects already counted from those still to be counted. In an example cited earlier, a child used his left hand to group objects already counted and his right hand to locate the next uncounted object.) While level two strategies help the child to coordinate the selection of a single object with the assignment of a single number name, they do not prevent the child from counting objects more than once.

At level three, children counted objects one at a time, coordinating the selection and tagging of objects. In addition they utilized some form of "movable partitioning system" to prevent the recounting of objects or the skipping of objects not yet counted.

Loose Arrays. As with the preliminary scanning and count organizing strategies, children who did not relocate objects were scored using the levels described for fixed arrays. Children who did relocate objects used one of the following three levels of partitioning strategies.

At level one, children relocated objects, but this relocation did not facilitate the selection of individual objects.

At level two, children picked up objects one at a time during the counting process, but returned objects to their original location after counting them. These children were more likely to count the same object several times because they did not partition objects already counted from those still to be counted.

At level three, children picked up objects one at a time, stating single numeral names and then placing objects down in a separate area of the tray. These children moved objects not only to aid in selecting them one at a time but also to prevent the recounting of objects.

Table 1

Posited Developmental Sequence for Preliminary Scanning Strategies

Level	Example
1 No Scanning	**Fixed Array** Child reached out and touched one object and immediately began to count. **Loose Array** Child reached out and moved one or several objects but did not relocate objects during the construction of correspondences.
2 Inefficient Scanning	**Fixed Array** Child reached out and moved hand across several objects in an unsystematic fashion and then began to count. Loose Array - (not applicable).
3 Efficient Scanning	**Fixed Array** Child reached out and swept hand across all objects in an organized systematic fashion before beginning to count. **Loose Array** Child reached out and moved one or several objects and went on to relocate objects during the construction of correspondences.

Table 2

Posited Developmental Sequence for Count Organizing Strategies

Level	Example
1 No Organization	Fixed Array Child did not select objects along row, circle, or from consistent area of random array. Loose Array Child did not move objects during count.
2 Inefficient Organization	Fixed Array Child followed row, circle or consistent area but did not use reference point to keep track of initial object counted. Loose Array - (not applicable).
3 Efficient Organization	Fixed Array Child followed row, circle or consistent areas using organizing reference point. Loose Array Child moved objects to new location during count.

Table 3

Posited Developmental Sequence for Partitioning Strategies

Level	Example
1 No Partitioning	Fixed Array Child stated several numerals as he touched a group of objects without one-to-one correspondence. Loose Array Child moved several objects at a time while he stated several numerals without one-to-one correspondence.
2 Inefficient Partitioning	Fixed Array Child counted one object at a time but did not use any form of movable partitioning system. Loose Array Child picked up objects but placed them back in original location during the count.
3 Efficient Partitioning	Fixed Array Child counted one object at a time using movable partitioning system. Loose Array Child moved one object at a time to separate area of tray while setting up one-to-one correspondences accurately.

Empirical Analyses of Developmental Differences in Blind Children's Counting Strategies

There were three objectives in the data analysis of strategic behaviors. The first objective was to provide evidence that bears on the adequacy of the developmental analysis proposed in the previous section. The primary analyses of interest for this objective were of data collected on blind subjects. However, analyses of blindfolded sighted subjects' strategies were used as another possible basis of empirical support for the posited sequence. The second objective of the data analysis was to investigate the consistency of strategic behavior across task conditions. The third objective of the data analysis was to explore developmental relations among the three dimensions of strategic behavior.

The experimenter observed the videotapes of blind and blindfolded-sighted children's counting using a stop action video monitor which allowed for careful analysis of verbal and gestural activities. These behaviors were assigned codes of from one to three for each of the three strategic dimensions on each trial, based upon the schemas summarized in tables 1, 2 and 3. Videotapes of 10% of the subjects were randomly selected and coded for all variables by an independent rater. Pearson product-moment correlations were computed for each of the three strategic dimensions. The correlations between the experimenter's and the independent rater's codings were Scanning (.86), Count Organizing (.79), and Partitioning (.80).

Adequacy of Proposed Developmental Sequence

Blind Subjects. Two sets of Pearson correlations were computed to assess the adequacy of the posited sequence for each dimension of blind children's counting strategies. These analyses included correlations between level of strategy use and two commonly accepted measures of development. The first set of correlations examined the relationship between children's age and the level of their strategy use. The correlations between age and strategy level were computed by summing strategy level scores across task conditions for each dimension, creating a total strategy score for that dimension, and computing correlations between each of these dimension totals and subject age computed in months. Correlations between age and strategy level were significant for each of the strategic dimensions: scanning, $r(22) = .56$, $p<.002$; organization, $r(22) = .39$, $p<.03$; and partitioning, $r(22) = .64$, $p<.001$.

The second set of correlations examined the relationship between children's counting accuracy and their level of strategy use. The correlations between counting accuracy and strategy level were computed by summing the total number of errors made across task conditions creating a total error score for each subject, and computing correlations between these total error scores and the total strategy scores for each dimension. Correlations between accuracy and strategy level were significant for each of the strategic dimensions: scanning, $\underline{r}(22) = -.80$, $\underline{p}<.001$; organization, $\underline{r}(22) = -.79$, $\underline{p}<.001$; and partitioning, $\underline{r}(22) = -.95$, $\underline{p}<.001$.

The significant correlations between strategy level use and both age and accuracy support the position that levels of each of the dimensions of strategic behavior described earlier do in fact represent steps in the development of efficient tactile strategic behaviors.

<u>Blindfolded-Sighted Subjects.</u> The blindfolded-sighted subjects were presented with all tasks on several consecutive days. The original plan was to administer the tasks on each of four days; however, after the second day most children refused to continue with the experiment and the number of days had to be reduced to two. It was initially hypothesized that, as subjects had more experience counting without the use of vision, they would develop more efficient tactile-strategic behaviors for each dimension. It was further hypothesized that this development would follow the same sequence as was identified for blind subjects. That is, if the levels outlined in the previous section do in fact represent a developmental progression toward more efficient tactile-strategic behavior, then blindfolded-sighted subjects should use higher level strategies on each successive day.

Initial observations of the videotapes of blindfolded-sighted subjects indicated their strategic behaviors could be categorized using the coding system developed for blind subjects. Each subject's counting behaviors were scored on each strategy dimension for both days. Total strategy level scores were computed for each dimension for both days by summing scores across all trials on that day. Each subject's total strategy level score for day two was compared to their score for day one, to determine if they had used higher or lower level strategies or if their score had remained the same. Contingency tables were created which indicated changes in strategy level scores for each strategic dimension between days one and two. Table 4 presents the findings for each of the three strategic dimensions as a function of age level. In order to have enough subjects in each cell to perform chi-square tests to determine if strategy level change between day one and two was significant, it was necessary to collapse subjects who showed no change together with those who changed to a less advanced level. The collapsed data is presented in Table 5. Chi-square anlayses were computed independently for each dimension. There were no significant differences between day one and two for any of the strategic dimensions. These findings do not provide any support for the hypothesis that blindfolded-sighted subject would develop more efficient tactile strategies with experience, although it is important to remember that the amount of experience provided in this study was minimal.

Table 4

Change in Strategy Level from Day One to Day Two: Change to Less Advanced and No Change Independent

	Age	Change to Less Advanced	No Change	Change to More Advanced
	4	3	3	9
Scanning	5	6	3	7
	6	4	5	7
	4	2	4	9
Organizing	5	3	2	11
	6	5	3	8
	4	1	7	7
Partitioning	5	2	4	10
	6	6	3	7

Table 5

Change in Strategic Level from Day One to Day Two: Collapsing Change to Less Advanced and No Change

	Age	No Change or Change to Less Advanced	Change to More Advanced
	4	6	9
Scanning	5	9	7
	6	9	7
	4	6	9
Organizing	5	5	11
	6	8	18
	4	8	7
Partitioning	5	6	10
	6	9	7

Consistency of Strategic Behavior

In order to investigate the stability of children's strategies across task conditions, a composite score based on the number of trials in which a child scored at each of the three strategic levels was computed for each dimension across task conditions. Scanning and partitioning scores are based on 24 trials, while count organizing scores are based on 18 trials (subjects were not scored for organizing on the homogenous random arrays since these arrays could not be organized). The highest percentage of consistent strategy achieved for any one strategic level was used as a measure of that subject's consistency. Based on these data, subjects were judged to be consistent or inconsistent strategy users. Table 6 presents the number of subjects demonstrating various levels of consistency for each of the three strategic dimensions. A contingency table was constructed to gain further insight into whether there were any differences between strategic dimensions. For the purpose of this analysis consistent strategy users were defined as being at the same level on 67% or more of the trials.

Table 7 presents the findings for each of the strategic dimensions. The data indicates that most subjects were consistent across task conditions for all three strategic dimensions. Children were most consistent in their use of partitioning strategies and least consistent in their use of organizing strategies.

Table 6

Frequency of Consistency Across Task Conditions for each Strategic Dimension

	Frequency						
	33-40	41-50	51-60	61-70	71-80	81-90	91-100
Scanning	1	1	3	4	4	2	9
Organizing	2	2	5	2	8	4	1
Partitioning	0	3	1	3	5	0	12

Table 7

Number of Children Showing Consistent and Inconsistent Strategy Use Across Task Conditions

	Consistent	Inconsistent
Scanning	16	8
Organizing	14	10
Partitioning	19	5

The differences in consistency between the three strategic dimensions can be interpreted by considering the function of each dimension in the counting process. Organizing strategies use physical characteristics of arrays to organize the counting sequence. Because different task conditions require that children use different types of organizing strategies, it is not surprising that we find the least consistency in that dimension. Partitioning strategies, on the other hand, deal with objects as individual entities and are independent of characteristics of the group. These strategies involve movement from one object to the next and focus on isolating objects in order to pair them with number names. As a result, this strategic dimension is not particularly affected by variations in the characteristics of the entire array as they change from task to task. Similiarly, scanning methods are generally applicable across arrays regardless of their particular characteristics, making this strategy consistently useful across task conditions.

Developmental Relationships Between Dimensions

Several contingency tables were constructed to gain insight into the order of emergence of strategic dimensions. In order to create these tables, subjects' total strategy scores were computed for each dimension by summing their scores across all task conditions on that dimension. The possible range of these scores was from 24 (if a subject received a 1 for each of the 24 trials) to 72 (if a subject received a 3 for each of the 24 trials) for the scanning and partitioning strategies. The range for organizing strategies was from 18 to 54; as indicated earlier, subjects were not scored for organizing on the homogeneous random arrays since these arrays could not be organized. The intervals for each level were arbitrarily determined by dividing the total possible range into three equal groupings (see tables 8,9,10).

Table 8

Strategy Level Comparisons for Organizing and Scanning in Blind Subjects

		Organizing		
Level		1 (18-29)[a]	2 (30-41)	3 (42-54)
Scanning	1 (24-39)	4	3	0
	2 (40-55)	0	3	2
	3 (56-72)	0	1	11

[a] Numbers in parenthesis indicate range of scores assigned to each level.

Table 9

Strategy Level Comparisons for Partitioning and Scanning in Blind Subjects

		Partitioning		
Level		1 (24-39)[a]	2 (40-55)	3 (56-72)
Scanning	1 (24-39)	5	1	1
	2 (40-55)	0	1	4
	3 (56-72)	0	0	12

[a] Numbers in parenthesis indicate range of scores assigned to each level.

Table 10

Strategy Level Comparisons for Organizing and Partitioning in Blind Subjects

		Organizing		
Level		1 (18-29)[a]	2 (30-41)	3 (42-54)
Partitioning	1 (24-39)	4	1	0
	2 (40-55)	0	2	0
	3 (56-72)	0	4	13

[a] Numbers in parenthesis indicate range of scores assigned to each level.

These contingency tables indicate that 19 out of 24 subjects were at the same level for partitioning and organizing, 18 out of 24 at the same level for partitioning and scanning, and 18 out of 24 at the same level for organizing and scanning. While most subjects were at the same level for each of the three dimensions, data on the small number of remaining subjects provides some information bearing on the order in which the three strategic dimensions may emerge during development. Based on data from subjects inconsistent in strategy level use, it may be inferred that partitioning strategies develop first, followed by organizing and finally by scanning strategies. A possible developmental relationship between scanning and organizing strategies is indicated in Table 8 above, which shows that, while five subjects scored higher on organizing than scanning, only one scored higher on scanning than organizing. Table 9 above indicates a possible developmental relationship between scanning and partitioning strategies. Six children scored higher on partitioning than scanning, while none scored higher on scanning than partitioning. Table 10 above indicates a possible developmental relationship between organizing and partitioning strategies. While four children scored higher on partitioning than organizing, only one scored higher on organizing than partitioning.

The above findings, which suggest a possible order of emergence in the use of different strategies, can be interpreted in terms of Saxe's (1977) model of strategic development. He suggested that the child's developing conceptual understanding of counting underlies the creation of mediating strategic behaviors. That is, as the child comes to understand the importance of accurate one-to-one correspondences, he creates strategies to ensure that accuracy. This model would be consistent with the observation that partitioning may precede the use of organizing and scanning strategies. Partitioning strategies appear first in development because these strategies focus on selecting objects one at a time and assigning single number names to these objects. Then, as children become more proficient in selecting individual objects, they become able to consider characteristics of the entire array and to use these characteristics to organize counting. Finally, after learning to use various task characteristics to organize the counting process, children develop strategies for scanning the array before beginning to count in order to determine which type of organizing strategy is more appropriate.

CHAPTER IV

Comparative Analysis of Counting Errors

The purpose of this chapter is to present a comparative analysis of the patterns of counting errors of blind, sighted and blindfolded-sighted subjects. An analysis of similarities and differences in error patterns of blind and sighted subjects addresses two general questions about the development of counting across population groups. Do conceptual errors precede implementation errors over the course of number development in both population groups? Are the nature of implementation errors different across populations groups? Finding that conceptual errors do precede implementation errors would be consistent with the position that children's counting does, in fact, undergo a qualitative change over the course of development and that such a change is not limited to a particular population group. Finding that blind and sighted groups make different types of implementation errors would be consistent with the position that errors described as implementation errors are in fact related to perceptual-motor skills.

Coding for Error Types

In the analysis of error types, errors were coded according to a schema derived from previous research and from observations of blind children's counting during the pilot study. Errors were attributed to one of two primary sources. The first source hypothesized to be related to children's counting errors was the level of their conceptual understanding of the logic underlying one-to-one correspondences (conceptual errors). The second source involved children's difficulty mastering the perceptual-motor skills used to implement their conceptual knowledge (implementation errors). Several types of implementation errors were distinguished based on the nature of the error (i.e., omission, recounting) and its location (i.e., center or the periphery of the array). Following is a description of each type of error.

Conceptual Errors

1) Many-to-One Correspondence - Child stated one or two number names while holding or touching many objects or stated many number names while touching or holding only one or two objects or stated many number names while holding or touching many objects without one-to-one correspondence.

Implementation Errors

2) Double count - Child counted an object in an array more than once consecutively.
3) Recount - Child returned to count an object already counted in a non-consecutive fashion after having counted the other objects in the array.
4) Internal Omission - Child omitted an object when those surrounding it had been counted.
5) Peripheral Omission - Child omitted an object at either the beginning or end of the counting path.

6) Overrun - Child stated number names after having finished touching or holding objects.

7) Asychrony - Child's tagging got out of step with partitioning during the counting process; child stated numerals without assigning them to objects.

Miscellaneous Errors

8) Order violation - Child used different lists of number words on separate counts.

9) Tag duplication - Child repeated a number name during a count.

10) Cardinality - Child gave either no cardinal response or stated a number different from the last number counted in response to the question "How many are there altogether?"

Modified Subject Grouping

It was necessary to divide both blind and sighted subject groups into subgroups in order to test within-group developmental hypotheses and to match subjects for between-group comparisons. The large discrepancy in age between the blind and sighted groups (blind subjects ranged from 3-6 to 13-11 while sighted subjects from 3-0 to 4-9), prevented age from serving as a viable criteria for matching. Because the goal of comparisons made between blind and sighted subjects was to compare their error patterns, a decision was made to form subgroups based on number of counting errors made. While number of errors does not qualify as an indicator of general cognitive level, it does reflect each subject's developmental position with respect to the cognitive ability under study (i.e. counting). The total number of errors made across all trials was computed for each subject. In order to determine cutoff points, a crosstabulation was made of error total by subject group (blind and sighted). Analysis of this crosstabulation revealed that subjects in each group could be divided into three "accuracy levels", with approximately one third of both blind and sighted groups falling into each level. The number of errors associated with each level were: level one: 50-213; level two: 10-49; and level three: 0-9.

Coding children's performance using the procedures detailed above allowed for a quantitative profile of each subject's counting behavior in terms of subject group, accuracy level, and the types of errors made. These profiles formed the basis for the analyses described in this chapter. Videotapes of 10% of blind, sighted and blindfolded-sighted subjects were selected at random and coded for accuracy level and error types by an independent rater. A Pearson product-moment correlation was significant (.82) between the experimenter's and the independent rater's codings.

The Conceptual Shift and Its Relationship to the Development of Strategic Behaviors

The analyses described in this section were performed in order to determine whether there is evidence of conceptual errors in children's counting, and, if there is such evidence, whether these errors are related to two other indices of number development: children's counting accuracy and children's counting strategies described in the previous chapter.

Children's Conceptual Errors in Counting. As discussed in the Introduction, it has been proposed that children's conceptual understanding of counting undergoes a qualitative shift in which counting develops from a non-numerical naming activity to a system of numerical representation. If this change or shift in fact occurs it should be reflected in the types of errors made by children prior to and after the shift occurs. Specifically, it was hypothesized in the present study that conceptual errors -- errors which indicate children do not understand the need for accurate one to one correspondences, (many-to-one correspondence errors) -- would make up a larger percentage of the total number of errors of younger, less accurate counters, while implementation errors -- errors which indicate children understand the need for constructing accurate one to one correspondences but have difficulty mastering the perceptual-motor skills necessary to implement that understanding, (double count, recount, overrun, asynchrony, internal and peripheral omission errors) -- would make up a larger percentage of the total number of errors of older, more accurate counters.

The percentage contributed by each error type to the total number of errors was computed for each subject. A "conceptual" error percentage score was formed which consisted of the percentage of many-to-one correspondence errors. An "implementation" error percentage was formed by combining the percentages for the six types of implementation errors. Table 11 contains mean percentage distributions for the two primary error categories as well as miscellaneous errors for both blind and sighted subjects as a function of accuracy level.

Table 11

Mean Percentage of Conceptual, Implementation and Miscellaneous Error Categories as a Function of Subject Group and Accuracy Level

	Accuracy Level	Conceptual	Implementation	Miscellaneous [a]
Blind	3 (0-9)	0	100	0
	2 (10-49)	0	100	0
	1 (50-213)	31	67	2
Sighted	3 (0-9)	0	98	2
	2 (10-49)	0	93	7
	1 (50-213)	16	67	17

[a] Miscellaneous category includes order violation, tag duplication and cardinality errors.

The data presented in Table 11 support the hypothesis that "conceptual" errors made up a larger percentage of the total number of errors of younger, less accurate counters, while "implementation" errors made up a larger percentage of the total number of errors of older, more accurate counters. Children at the first accuracy level in both groups made conceptual errors. This suggests that they do not understand the necessity of accurate one-to-one correspondences. The children at the second and third accuracy levels understand the logic of counting and recognize the need for making accurate correspondences, but have difficulty with the perceptual-motor coordination necessary to implement their understanding.

The Relationship Between Conceptual and Strategic Development

As mentioned in the introduction, it has been suggested that children's development of strategic behavior is in part based on their conceptual understanding of counting. Children who do not understand the reason for constructing accurate correspondences are unlikely to create strategies designed to ensure the accuracy of these correspondences. As children come to understand the logic underlying counting, they recognize the need for accurate correspondences and create more efficient strategies. It was hypothesized that children who use lower level strategies would have a higher percentage of conceptual errors (many-to-one correspondence errors) than would children who use higher level strategies. Table 12 contains mean percent distributions for the two primary error categories as well as miscellaneous errors as a function of strategy level for each of the three strategic dimensions. The observation of "conceptual" errors in children using level one strategies suggests that these children have not yet developed a stable understanding that counting requires the construction of accurate one-to-one correspondences. The complete absence of "conceptual" errors in children using level two scanning and partitioning strategies and the low percentage of "conceptual" errors in children who use level two organizing strategies implies that children at the second level understand the need for accurate correspondences and have created strategies to facilitate counting accuracy. It appears that any change which takes place between levels two and three involves the development of more efficient strategies rather than changes in children's conceptual understanding of counting as a means to represent number.

Table 12

Mean Percent Distribution of Error Categories by Strategy Level for Blind Subjects

	Scanning			Organizing			Partitioning		
Strat Level	Con	Imp	Misc	Con	Imp	Misc	Con	Imp	Misc
3	0	100	0	0	100	0	0	100	0
2	0	100	0	6	94	0	0	100	0
1	36	63	1	52	45	3	50	48	2

a Miscellaneous category includes order violation, tag duplication and cardinality errors.

Influence of Perceptual-Motor Systems on Counting Performance

The analyses described in this section were performed in order to determine whether the use of strategies that depend on input from different sensory systems (tactile versus visual) by blind and sighted subjects has a differential impact on counting performance. Two sets of analyses were performed. The first set focused on differences in error patterns among blind, sighted and blindfolded-sighted subjects. The second set focused on the effect of variations in task conditions (object mobility, configurational arrangement) on the counting accuracy of blind and sighted subjects. The results of these analyses are used to make inferences about the influence of congenital blindness on children's counting performance, as well as the relationship between children's counting errors and perceptual-motor skills.

Several specific hypotheses were proposed concerning expected differences in error patterns. The first hypothesis predicted that there would be no significant differences in the number of order violation or tag duplication errors between blind and sighted subjects. The second hypothesis predicted that blind children would have more recount and peripheral omission errors and fewer double count and internal omission errors than sighted children.

Percentage scores were computed which reflect the number of times a subject made each particular type of error. These scores were created by dividing the number of times a subject made a particular error type across trials by their total number of errors. The scores of subjects in each of the population groups were combined to yield group profiles. These group percentage profiles are presented in Table 13. Examination of this table reveals that no subjects in either the blind or sighted groups made any order violation or tag duplication errors. This finding supports the hypothesis which predicted that there would be no differences between the two groups in the percentages of these types of errors. The finding that all subjects in both groups counted using a stable list of number names, and did not repeat any of those names during a count, indicates that neither blind nor sighted children, even those who made a large number of errors, had difficulty with these aspects of counting.

Comparisons made between blind and sighted groups using eight oneway analyses of variance tests indicated that blind subjects made more internal omission, $\underline{F}[1,44] = 5.03$, $\underline{p}<.03$, and peripheral omission, $\underline{F}[1,44] = 32.74$, $\underline{p}<.001$, errors than did sighted subjects. Sighted subjects made more double count, $\underline{F}[1,44] = 9.59$, $\underline{p}<.003$, recount, $\underline{F}[1,44] = 15.47$, $\underline{p}<.001$, overrun, $\underline{F}[1,44] = 4.68$, $\underline{p}<.03$, and cardinality, $\underline{F}[1,44] = 6.38$, $\underline{p}<.01$ errors than did blind subjects. There were no significant differences between groups in many-to-one correspondence or asynchrony errors.

The findings regarding error patterns reveal both similiarities and differences between blind and sighted subjects. While the hypothesis that blind children would have more recount and peripheral omission errors and fewer double count and internal omission errors than sighted children was not supported, results indicate the presence of differences in error patterns between blind and sighted subjects.

Table 13

Blind and Sighted Subjects' Percentage of Each Error Type

Accuracy Level	D.C.[a]	Rec	I.O.	P.O.	Many To One Corr	Over	Asyn	Card	Tag Dup	Ord Vio
Blind	5	22	24	38	10	0	1	0	0	0
Sighted	15	49	9	4	7	2	4	10	0	0

[a] D.C.=(Double Count), Rec.=(Recount), I.O.=(Internal Omission), P.O.=(Peripheral Omission).

Several data modifications were performed in order to gain further insight into differences noted in error patterns between blind and sighted subjects. First, subjects in each population group were divided into the three levels of accuracy described earlier. Second, error types were collapsed to form a smaller number of groupings. Visual inspection of Table 13 suggested common features of error types which were prominent in each of the two groups. These common features were used as the basis for collapsing the eight error types into three categories. Specifically, recount, double count and overrun errors were combined and labelled "count again" errors, that is, errors in which the subject counts the same object twice. Internal and peripheral omission errors were also combined and labelled "omission" errors, that is, errors in which the subject fails to count an object. Table 14 contains the mean percent distribution for "count again" and "omission" errors as a function of counting accuracy of blind and sighted subjects.

Three oneway analysis of variance tests compared blind and sighted groups for count again, omission and miscellaneous errors. These analyses indicated that blind subjects made more omission errors than sighted subjects, $\underline{F}$ [1,48] = 45.84, $\underline{p}$ <.001, while sighted subjects made more count again errors than blind subjects, $\underline{F}$ [1,48] = 23.59, $\underline{p}$ <.001. There was no significant difference between groups in miscellaneous errors. Performing statistical analyses of differences in the three error categories as a function of the three levels of counting accuracy would be inappropriate, because these levels represent a categorization of the dependent variables. However, an inspection of Table 14 indicates that both blind and sighted subject groups tend to produce group specific error patterns as they become more accurate counters. Blind subjects made more "omission" errors, while sighted subjects made more "count again" errors. In other words, although the total number of errors made by both groups decreased from level one to level three, subjects at higher (more accurate) levels made a higher percentage of errors characteristic of their group as a whole and fewer errors associated with the other group.

The only inconsistency in the pattern identified above occurs in the percentage of "count again" errors in blind and "omission" errors in sighted subjects at level one, where the percentages are lower than expected. However, it is important to note that many-to-one correspondence errors account for a large percentage of errors at level one. The previous discussion suggested that subjects who made many-to-one correspondence errors do not yet have a mature understanding of the logic of one-to-one correspondences. Their errors could therefore be the result of conceptual as well as perceptual-motor difficulties.

Table 14

Percentages of Count Again and Omission Errors for Blind and Sighted Subjects

	Blind			Sighted		
Accuracy	Count Again	Omission	Misc a	Count Again	Omission	Misc
3 (0-9)	16	84	0	90	2	4
2 (10-49)	44	54	1	69	17	12
1 (50-213)	19	47	35	45	16	36
Group	26	62	12	66	14	21

a. Miscellaneous category includes asynchrony, cardinality and many-to-one errors.

In summary, data collected in the present study indicates that blind and sighted subjects exhibit similiar patterns of counting development. Many-to-one correspondence errors were present in both blind and sighted groups, but at level one only. This finding was interpreted above as evidence that beginning counters, both blind and sighted, initially do not understand the need for constructing one-to-one correspondences. The finding that many-to-one correspondence errors did not occur at levels two and three in either group suggests that subjects at both these levels have attained a more advanced understanding of the logic of one-to-one correspondences. The counting errors made by these subjects is attributable to difficulties they have implementing their conceptual knowledge. The finding that blind and sighted subjects made different types of implementation errors supports the position that implementation errors are the result of difficulty mastering perceptual-motor skills.

Errors of blindfolded-sighted subjects. The types of errors made by blindfolded-sighted subjects were compared to those made by blind and sighted subjects. Results indicated that blindfolded-sighted and blind subjects exhibited similiar patterns with respect to count again and omission errors. The error pattern of the sighted group differed significantly from the other two groups.

Percentages of each error type were computed for blindfolded-sighted subjects. None of the blindfolded-sighted subjects made order violation or tag duplication errors. The percentage contributed by the remaining error types to the total number of errors is shown in table 15.

Table 15

Percentage of Each Error Type by Group

Group	D.C.	Rec.	I.O.	P.O.	Many To One Corr	Over	Asyn	Card	Tag Dup	Ord Vio
Blind	05	22	24	38	10	00	01	00	00	00
Sighted	15	49	09	04	07	02	04	10	00	00
Blind-folded-sighted	05	15	31	40	07	00	01	00	00	00

a D.C.=(Double Count), Rec.=(recount), I.O.=(Internal Omission), P.O.=(Peripheral Omission).

Errors made by blindfolded-sighted subjects were compared with those made by the blind and sighted groups. In order to make these comparisons the errors of blindfolded-sighted subjects were collapsed into the three groupings used to compare blind and sighted groups (i.e., count again, omission and miscellaneous). Three oneway analysis of variance tests determined whether blind, sighted and blindfolded-sighted subject groups differed in their percentages of count again, omission or miscellaneous errors. Results indicated a significant difference in count again errors, $\underline{F}$ [2,94] = 29.30, $\underline{p}$ <.001, and omission errors, $\underline{F}$ [2,94] = 41.06, $\underline{p}$ <.001. There were no significant differences in miscellaneous errors. Post-hoc analyses using the Scheffe method revealed that sighted subjects differed significantly at the ($\underline{p}$<.05) level from both blind and blindfolded sighted subjects on count again and omision errors, while blind and blindfolded-sighted subjects did not differ significantly from one another on either of these error type groupings. The finding that blindfolded-sighted subjects who, like blind subjects, used tactile-motor skills to count the arrays in the present study, had errors similiar to those of blind subjects but different from those of sighted subjects provides further support for the position that implementation errors result from difficulties related to perceptual-motor skills.

Variations in Task Characteristics. The analyses described in this section provide a further opportunity to investigate the position that characteristics of perceptual-motor systems influence counting performance. Comparisons were made to determine whether varying task characteristics (object mobility, array configuration) resulted in differences in the performance of children who depend on different perceptual-motor systems (blind and sighted subjects).

Object mobility. On half of the trials, objects were fixed to sheets of plywood, thus preventing children from moving them during a count. On the other half of the trials, objects were presented loose in trays so that children could move them. It was expected that the opportunity to relocate objects during a count would facilitate counting accuracy. Several specific hypotheses were tested. The first hypothesis tested was that both blind and sighted subjects would be more accurate on the loose than the fixed arrays. The second hypothesis tested was that this difference in accuracy would be greater for blind than sighted subjects.

Table 16 contains the mean number of errors made by blind and sighted subjects as a function of accuracy level and object mobility. A 2 (population group) x 3 (accuracy level) x 2 (mobility) repeated measures analysis of variance, with mobility serving as the repeated measure, revealed no main effect for population group, but one for mobility, F [1,44] = 3.94, p <.05, and for accuracy level, F [2,44] - 63.59, p <.001. The effect for mobility indicated that subjects had significantly fewer errors on loose than fixed arrays. The effect for accuracy level is inherent in the criteria for the construction of the groupings themselves and needs no explanation. There were significant interactions between population group and mobility, F [1,44] = 4.91, p <.03, and between accuracy level and mobility, F [2,44] = 4.69, p <.01. Further analysis of the simple main effects for the interaction between group and mobility indicated the difference in mobility was significant for blind subjects, F [1,46] = 8.75, p <.01, but not for sighted. That is, blind, but not sighted, subjects made significantly fewer errors on loose versus fixed arrays. Further analysis of the simple main effects for the interaction between accuracy level and mobility indicated the difference in mobility was significant for subjects at accuracy level two, F [1,30] = 59.42, p <.001, but not significant for subjects at accuracy levels three or one. That is, subjects at accuracy level two made significantly fewer errors on loose versus fixed arrays. Although the three way interaction was not significant at the .05 level (p <.10), an inspection of Table 16 indicated that the difference at accuracy level two occurred primarily in blind subjects.

Table 16

Average Number of Errors for Blind and Sighted Subjects by Object Mobility

	Accuracy Level			
Mobility	3	2	1	Group
Blind				
Fixed	2.50	23.38	61.75	29.21
Loose	1.75	5.38	60.75	22.63
Sighted				
Fixed	2.50	12.89	40.00	21.96
Loose	2.67	11.44	42.36	22.50

These findings give partial support to the first hypothesis and full support to the second. Specifically, blind subjects had significantly fewer errors on loose than on fixed arrays, while sighted subjects made equal numbers of errors under the two conditions. Further examination of strategies used by sighted subjects provides an explanation for this finding. This examination indicated that sighted subjects did not take advantage of the opportunity to move objects in loose arrays. Instead they approached loose arrays as they had fixed arrays, using pointing gestures under both conditions.

The analyses of simple main effects for the interaction between accuracy level and mobility indicated that the difference in mobility was significant only for the level two group. The absence of a significant difference for level one counters may reflect their inability to use relocation as a mediational aid to their counting. Children at level two relocated objects to improve their counting accuracy. The absence of a significant difference for level three counters may reflect the fact that in the most accurate counters non-relocation strategies had been developed to the extent that they functioned as efficiently as the relocation strategies. This would explain why this group of subjects made few errors under both conditions.

Configurational arrangement. Analyses were conducted to determine whether varying configurational arrangments would differentially affect the counting accuracy of blind and sighted subjects. Arrays were constructed in four different configurations (linear, circular, homogenous random and heterogeneous random). It was expected that different arrangements would offer a variety of aids and obstacles to counting, and that blind and sighted children's counting strategies would respond differently to those variations. There were no specific hypotheses concerning configurational arrangment.

Table 17 contains the mean number of errors for blind and sighted children as a function of mobility and configurational arrangement. A 2 (population group) x 2 (mobility) x 4 (configuration) repeated measures analysis of variance with mobility and configuration serving as the repeated measures revealed no main effects for population group or mobility, but one for configuration, F [3,144] = 8.49, p <.001. There were significant two way interactions between population group and mobility, F [1,48] = 4.42, p <.04, and between population group and configuration, F [3,144] = 3.06, p <.03. There was also a significant three way interaction between population group, mobility and configuration, F [3,144] = 3.30, p <.02.

Further analysis of simple main effects for the interaction between group and mobility were already discussed in the previous section. Further analysis of simple main effects for the interaction between population group and configuration indicated differences between blind and sighted subjects for homogeneous random, F [1,98] = 8.16, p <.001, and heterogeneous random, F [1,98] = 23.05, p <.001, but not for linear or circular arrays. That is, sighted subjects made significantly fewer errors under both random array conditions. A simple main effects analysis performed to determine differences between configurations within population groups revealed that sighted subjects but not blind subjects made significantly fewer errors on heterogeneous random arrays than on homogeneous random arrays, F [1,102] = 7.50, p <.01. There were no differences in the number of errors for either blind or sighted subjects between circular and homogeneous random arrays. Sighted subjects made significantly fewer errors on heterogeneous random than circular arrays, F [1,102] = 5.65, p <.05. Both blind, f [1,94] = 6.60, p <.01, and sighted, F [1,102] = 7.90, p <.01, subjects made significantly fewer errors on linear than circular arrays.

Further analysis of simple main effects for the three way interaction between population group, mobility and configuration indicated a signficant difference for blind, but not sighted, subjects on three configurations for fixed versus loose arrays. Blind subjects made significantly fewer errors on circular, homogeneous random and heterogeneous random fixed arrays, than the equivalent configurations for loose arrays, but not for linear fixed versus loose arrays.

The analysis of the three way interaction supports the finding of the previous analysis that blind, but not sighted subjects made significantly fewer errors on loose versus fixed arrays. The one exception to this general finding is that there was no significant difference between the number of errors blind subjects made on fixed versus loose linear arrays. This finding can be interpreted in terms of the relative ease of counting fixed linear arrays. Linear arrays provide clear beginning and end points for the counting procedure which are not present in the other arrays. This interpretation is supported by the finding that both blind and sighted subjects had fewer errors on linear arrays than any other configuration. It appears that the use of these starting and stopping cues made counting fixed linear arrays as easy for blind subjects as did the relocation strategies they used on the loose arrays. The analysis of the two way interaction between population group and configuration revealed similiar profiles for blind and sighted subjects. The one exception to this generalization is that sighted children utilized subgroupings in the random heterogeneous arrays to improve the accuracy of their counting. The fact that blind subjects did not use subgroupings in the array to facilitate counting suggests that the visual-perceptual cues were more tangible than the tactile-perceptual cues.

Table 17

Average Number of Errors for Blind and Sighted Subjects by Configurational Arrangement

	Fixed Arrays				Loose Arrays			
Group	Linear	Circle	Homo Rand	Hete Rand	Linear	Circle	Homo Rand	Hete Rand
Blind	4.50	7.79	8.33	8.58	4.96	5.71	5.75	6.21
Sighted	4.88	5.81	6.81	4.46	4.04	7.04	6.58	4.85

CHAPTER V

General Discussion and Conclusion

The present study was an investigation of the counting behaviors of congenitally blind subjects and a comparison of their counting performance with that of sighted and blindfolded-sighted subjects. The findings of this investigation provide both a detailed description of the development of counting abilities in blind children, and comparative data which bears on several questions that have emerged from studies of counting abilities in sighted children.

The following discussion summarizes the results of the present study. This discussion is divided into five sections. The first section discusses findings on the development of counting stratagies in blind children. The second section discusses findings concerning conceptual development and its relationship to strategic development. The third section discusses findings on differences and similiaraties in the counting performance of blind and sighted subjects. The fourth section considers the delay in acquisition of counting skills observed in blind children. The final section is a conclusion section, this section summarizes and combines the results of the previous sections.

The Development of Tactile-motor Counting Strategies in Blind Children

Chapter three discussed the strategic behaviors blind children use to facilitate counting accuracy. Two areas of previous research provided a background for initial observations of counting behaviors in blind children. First, research on visual-motor counting strategies used by sighted children suggested that sighted children employ a number of strategies such as pointing (Saxe and Kaplan, 1981) and the use of characteristics of objects and arrays (Beckwith and Restle, 1966; Schaeffer et al., 1974) to assure the accuracy of their counting. Strategies are used to select a single object from the array, coordinate the selection of that object with the selection of a single number name from an available list, and partition objects already counted from those still to be counted. Second, research on the use of tactile strategic behaviors by blind children and adults (Davidson, 1972; Davidson and Whitson, 1974; Davidson, Dunn, Wiles-Kettenmann and Appelle, 1981) suggested that blind individuals use tactile-motor strategies to assist their performance on cognitive tasks.

Using the two areas of research mentioned above as a guide, initial observations of blind children's counting focused on identifying the tactile-motor strategies blind children create to facilitate counting accuracy. Strategies were then analyzed to determine their individual functions, their consistency across variations in task conditions and their place within a general strategic system.

Observations of blind accurate counters (children who made an average of less than one error per trial) revealed a variety of behaviors that were divided into three strategic dimensions, e.g., "preliminary scanning", "count organizing" and "partitioning" strategies. Each dimension served a discrete function in an overall network of strategic behaviors. Scanning strategies preceeded the construction of the first one-to-one correspondence. These strategies provide information about the physical characteristics of individual objects and the array as a whole that could be used to organize the count sequence. Two types of strategic behaviors, count organizing and partitioning strategies appeared during counting. Count organizing strategies dealt with objects as members of a group and served to organize the counting sequence using physical characteristics of the array such as linearity. Partitioning strategies dealt with objects as discrete elements. These strategies appeared within count organizing strategies. For example, when children counted along a row (count organizing strategy) they used some type of movable partitioning system to select objects one at a time and partition objects already counted from those still to be counted. Behaviors used to select individual objects were labeled partitioning strategies.

Specific counting behaviors observed in less accurate counters were identified as precursors of the efficient "endpoint" strategies used by accurate counters. A sequence of levels was posited for the development of each of the strategic dimensions. Two sets of correlations tested the adequacy of the posited sequences. Correlations examined the relationship between children's strategy level for each dimension and both age and counting accuracy. Both sets of correlations were found to be significant, thus supporting the position that the posited sequence of strategy levels represented steps in the development of efficient tactile-motor strategies.

Consistency of strategy use across task conditions was examined for each strategic dimension. Results indicated that most subjects were consistent across task conditions for all three strategic dimensions. The finding that strategic consistency varied among the three dimensions suggests that, although there is consistency, task characteristics do have some influence on the application of these strategies. The finding that children were more consistent in using partitioning than scanning strategies and in scanning than organizing strategies was attributed to differences in the functions of these strategic dimensions. That is, organizing strategies which use physical characteristics of arrays to organize the counting sequence, must be tailored to the demands of each task condition. The need to create varying task-dependent strategies leads to the lower consistency found within this dimension. In contrast, scanning strategies are generally applicable across task conditions (i.e., a single scanning behavior can identify the circularity or linearity of an array) and subjects were more likely to be consistent on this dimension. Finally, the purpose of partitioning strategies is to isolate an individual object and pair it with a single number name. Because this type of activity deals with objects as individuals rather than as members of an array it was not influenced by variations in the overall array configuration and as a result was the most consistent dimension.

Regarding the issue of a possible developmental progression in the emergence of strategic dimensions, it was found that most children functioned at the same level across the three dimensions. Some variation did occur, with more children functioning at a higher level on partitioning relative to organizing or scanning, and at a higher level on organizing relative to scanning. This variation was interpreted in terms of children's developing conceptual understanding of counting as a mechanism that underlies their creation of mediating strategic behaviors. According to Saxe's model (Saxe, 1979), children's developing construction and coordination of operations of successive iteration and progressive summation enables them to understand the importance of constructing accurate one-to-one correspondences and leads them to create strategies to facilitate the pairing of individual objects with single number names. This suggests that the first strategic dimension to develop should be one that focuses on selecting individual objects one at a time, enabling children to assign a single number name to that object (partitioning). Later, after children become proficient at constructing individual correspondences, they are then able to focus on characteristics of the array as a whole and to use these characteristics to organize the count (count organizing). Finally, after learning to use a variety of count organizing strategies suitable under different task conditions, children begin to develop strategies for scanning the array (scanning) before counting in order to determine the appropriate organizing strategy.

Conceptual Development and its Relationship to Strategic Development

The purpose of this analysis was to determine if children's conceptual understanding of counting changes during development and if this change in understanding is a mechanism that underlies children's development of strategic behavior. As noted previously, researchers differ in their views of the numerical significance of young children's counting. Piaget (1952) suggested that preschool children's counting is a rote recitation of number words having no numerical meaning. On the other hand, Gelman (Gelman and Gallistel, 1978) holds that children as young as two have an understanding of the logical principles underlying counting and that their counting therefore has numerical significance. A third alternative has been suggested by Saxe (Saxe, 1979). In his model, young children acquire a list of number names which they learn to apply in a stable fashion. Initially the child uses this list as part of a naming activity, referring names (number words) to objects. This use of counting as a naming activity does not have any numerical significance. As children come to understand the logic of counting and its dependence on accurate one-to-one correspondences, a shift occurs in their conceptual understanding. With this shift their counting takes on numerical significance and becomes a tool used to represent quantity.

Several studies have used children's counting errors to assess or measure their conceptual understanding of counting (Gelman and Gallistel, 1978; Wilkenson, 1984; Saxe, 1977). Certain types of errors indicate that children do not understand the necessity of making accurate correspondences (conceptual errors), while other types of errors indicate that children do understand the importance of accurate correspondences, but have perceptual-motor difficulties implementing that understanding (implementation errors). In the present study, counting errors of blind and sighted subjects were used to determine the adequacy of Saxe's model, which suggested that conceptual errors (errors indicating children's counting does not have any numerical significance) would make up a larger percentage of the errors of younger, less accurate counters than they would of older, more accurate counters. Conceptual errors were found in the error patterns of younger, less accurate blind and sighted counters but not in the error patterns of older, more accurate counters.

While these data are consistent with Saxe's model suggesting a developmental shift in children's conceptual understanding of counting, they are not in themselves conclusive evidence of this shift. Several issues limit the strength of the present analysis. First, the understanding of the logic underlying one-to-one correspondences is only one of several aspects of a conceptual understanding of counting (others include cardinality, and the ability to use counting in number related tasks). Future research should consider children's understanding of these additional aspects as well as their understanding of the logic underlying one-to-one correspondences. Second, although a percentage of both blind and sighted subjects at accuracy level one made errors which were conceptual errors (blind = 31%, sighted = 16%), both groups also made a large number of implementation errors suggesting some understanding of one-to-one correspondence. Additional research is necessary to determine why some subjects make both conceptual and implementation errors.

Saxe (1977) suggested that this shift in the conceptual understanding of counting is a mechanism underlying the development of strategic behaviors. He argued that, because young children do not use counting to represent the number of objects in an array, there is no reason for them to create strategies to assure the accuracy of counting. However, once children do understand that representational counting requires that number names be applied in one-to-one correspondence they construct strategic behaviors to facilitate counting accuracy. In the present study analyses were performed which compared the percentage of conceptual and implementation errors made by children at each strategy level for each of the three strategic dimensions. Children who made conceptual errors (indicating they did not understand the need for accurate correspondences) used level one strategies, that is, strategies which did not facilitate the construction of correspondences. Children who did not make conceptual errors used level two and three strategies, that is, strategies which were more effective in assuring counting accuracy. The progression from level two to level three strategies was attributed to the identification of more efficient strategies through experience rather than to a change in conceptual knowledge. While these findings are consistent with Saxe's position, the need for additional measures of conceptual understanding and further investigation of the presence of both conceptual and implementation errors in level one counters limits the support provided by the present analysis.

Differences in Counting Errors of Blind and Sighted Subjects

The purpose of this analysis was to identify differences and similiarities in the counting performance of blind and sighted subjects, providing evidence bearing on two issues: the nature of differences in counting behaviors between the two groups and whether children's counting errors are the result of difficulty they have mastering perceptual-motor skills. Gibson (1962) has suggested that each sensory system has its own special sensitivity to the properties of a surface, e.g., visual perception obtains information in a simultaneous fashion while tactile perception obtains information successively. Piaget and Inhelder (1964) investigated the relationship between the simultaneous and successive characteristics of visual and tactile perception and conceptual development. They found that certain cognitive activites were facilitated while others were delayed when subjects utilized different sensory systems to perform tasks. In the present study several analyses were performed to determine whether the use of strategies depending on input from different sensory systems (tactile versus visual) has a differential impact on counting performance. One set of analyses examined differences in error patterns among blind, sighted, and blindfolded-sighted subjects. The second set examined the impact of variations in task conditions on the counting accuracy of blind and sighted subjects.

Analyses of error patterns suggested that both blind and sighted children progress through similiar patterns of development, with differences becoming more pronounced as children become more proficient counters. Results indicated that all subjects in both groups, regardless of counting proficiency, used stable lists of number names without repeating names during a count. This finding indicates that neither group had any particular difficulty with these two aspects of counting. Further comparisons of error patterns for children at three accuracy levels revealed similiar patterns of development. In both groups younger, less accurate counters made "conceptual" errors indicating a failure to understand the logic underlying counting. This finding has been interpreted as evidence that both blind and sighted children pass through an initial period of development during which counting is part of a naming activity having little, if any, numerical meaning. Older, more accurate counters no longer made "conceptual" errors. Their errors resulted from perceptual-motor difficulties implementing their conceptual knowledge. Comparisons made between older, more accurate blind and sighted subjects revealed that errors characteristic of these two groups began to diverge at this stage; that is children tended to produce group specific error patterns as they became more accurate counters. Blind subjects made more "omission" errors, while sighted subjects made more "count again" errors. The finding that children who use strategies depending on input from different sensory systems make different types of errors supports the position that the errors made during this stage are related to deficiencies in perceptual-motor skills.

Additional support for the above position was provided by comparing errors made by blindfolded-sighted, blind and sighted subjects. These comparisons revealed that blindfolded-sighted subjects, who were forced to rely on tactile-motor strategies, had error patterns similiar to those of blind subjects but different from error patterns of sighted subjects, who relied on visual-motor strategies.

A further opportunity to investigate whether characteristics of perceptual-motor systems influence counting performance was provided by comparing the impact of variations in task characteristics on counting performance of blind and sighted subjects. Tasks varied on two dimensions, object mobility and array configuration. For half the arrays, objects were loose and could be moved around during the counting operation. For the other half, objects were fixed to boards and could not be moved. Arrays were presented in four configurations--linear, circular, homogeneous random and heterogeneous random--within both fixed and loose conditions.

Comparisons of accuracy under the two conditions of object mobility found fewer errors on loose compared with fixed arrays for blind subjects, but no difference in accuracy for sighted subjects. Comparisons of accuracy under the four types of configurational arrangement revealed that both blind and sighted groups were more accurate on linear than on circular, random homogeneous or random heterogeneous arrays. The only difference between the groups appeared on the random heterogeneous arrays. Sighted subjects were more accurate on the random heterogeneous arrays than on either the circular or random homogeneous arrays, while blind subjects were not. This suggests that sighted subjects had an advantage over blind subjects in being able to utilize the subgrouping feature to improve the accuracy of their counting. The visual perceptual cues provided by the subgroupings may have been more tangible than the tactile-perceptual cues.

The finding that blind and sighted subjects responded differently to the variations in characteristics of the arrays involved in different task conditions provided further support for the position that characteristics of sensory systems influence counting performance and that many of children's counting errors may be attributed to perceptual-motor difficulties.

been better if the experimenter had tested each child personally using some form of general cognitive assessment device. The difficulties in attaining an accurate assessment of cognitive abilities in blind children is discussed at length by Warren (1977). He concludes that tests presently used to assess intelligence in blind children are not reliable or valid enough to be used with confidence. Many of the Verbal tests contain items inappropriate for blind children. In addition, cultural bias, which is always a problem in intelligence testing is a particular problem in the case of the blind, whose experience with some areas of cultural content is very sparce. With respect to Performance tests, Warren suggests that the measures which currently exist require extensive validity testing before they can be used with any confidence.

If an accurate assessment of cognitive abilities in the blind subjects relative to the general blind population could have been determined, the problem with comparing blind children's abilities with those of sighted children would still exist. Summarizing the findings related to the comparative intelligence of blind and sighted children, Warren indicates it is difficult if not impossible to make direct comparisons on tests which adequately cover the range of abilities considered to be part of the overall notion of intelligence. While blind children have an advantage on some tasks, sighted children have an advantage on others.

He goes on to point out that if we consider intelligence to be the abilitiy of individuals to adapt to their environment, then the adaptive needs of blind and sighted children are different and the issue of whether their adaptation is equally adequate cannot be assessed by simply administering a common test.

These issues demonstrate the difficulties inherent in determining the cognitive abilities of blind relative to sighted subjects. It is important to bear in mind that, although the subject selection process was not based on similiar data across subjects, each agency reviewed the records of possible subjects to assure they met stated criteria. Given that the performance of all of the 24 blind subjects was delayed relative to sighted subjects it is unlikely that all were inaccurately assessed. Alternative explanations for the delay of counting abilities in blind subjects must be considered. It is possible that some feature or features of the counting tasks employed in the present study may have presented specific difficulties for blind subjects. Another possibility is that, due to the avalability of only limited perceptual information, blind children may be delayed in the performance of all tasks which require the manipulation of physical objects. This hypothesis could be investigated in future research by comparing blind and sighted subjects' performance on a variety of tasks using perceptual-motor versus verbal assessments of a given cognitive process.

Whatever the source of the delay in blind subjects' mastery of counting skills, it does not invalidate the results of the comparative analysis used in the present study. The comparisons used in these analyses were comparisons of qualitative patterns of development, not of quantitative measures of performance. These comparisons were made between subjects matched based on their level in the development of a specific cognitive skill (i.e., counting). Each subject's counting errors were used to determine their counting proficiency and subjects were matched based on that proficiency. The results of the present study support the rationale behind this approach. Despite the significant difference in age range of the two groups, both progressed through similiar patterns of conceptual development. This finding has been discussed as evidence that the conceptual development of congenitally blind and sighted subjects is qualitatively identical. The differences lie in the problems both groups experience when implementing their conceptual knowledge through perceptual-motor systems.

Conclusion

The present study documented a system of interrelated tactile-motor strategies which blind children use to facilitate the accuracy of their counting. These strategies develop gradually and are, at least in part, based on blind children's developing conceptual understanding of counting as a system of numerical representation. As counting changes from being a non-numerical naming activity to an activity with numerical significance, blind children begin to create tactile strategies to ensure the accuracy of one-to-one correspondences.

Comparisons made of blind and sighted subjects' counting performance demonstrated that both groups progress through similiar patterns of development. While younger, less accurate counters in both blind and sighted groups made errors reflecting their lack of awareness of the importance of constructing accurate one-to-one correspondences, older, more accurate counters made errors reflecting their difficulty mastering the necessary perceptual-motor skills. Different types of implementation errors predominated in error profiles of blind and sighted subjects. These differences can be attributed to qualitative differences in the input provided by visual and tactile perception. Visual perception provided input in a "simultaneous" fashion, while tactile perception provided input in a "successive" fashion. The finding that a variation in the characteristics of the sensory input affected the occurrence of errors categorized as "implementation" errors supported the postion that these errors are the result of difficulty children have mastering perceptual-motor skills.

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