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Strauss, Mark S., and Curtis, Lynne E. *Infant Perception of Numerosity.* Child Development, 1981, 1146–1152. A multiple habituation paradigm was used to determine whether 10–12-month-old infants were able to discriminate between visual arrays which differed only in their numerosity (2 vs. 3, 3 vs. 4, or 4 vs. 5 items). 96 infants were tested in one of two conditions. In the heterogeneous condition, infants were habituated to a series of slides in which only the number of items remained invariant, while the item type (e.g., dogs, houses, etc.), size, and position varied on each slide. In the homogeneous condition, both the item type (chicks) and number remained invariant, while the size and position of the stimuli varied. Infants in both conditions were then tested with slides which contained either $N + 1$ or $N - 1$ items. The results demonstrated that, regardless of condition (homogeneous/heterogeneous), infants were able to discriminate between 2 and 3 items and unable to discriminate between 4 and 5 items. For the 3 versus 4 discrimination, a condition × sex interaction indicated that females discriminated between the items in the homogeneous condition while males were able to make the discrimination in the heterogeneous condition. Since the subjects in this study were preverbal infants, the results suggest that early counting skills are preceded by a more perceptual awareness of numerosity.

By the time most children enter school, they possess a rudimentary knowledge of the number system. Empirical interest in the origins of this knowledge extends to the early 1900s (e.g., Beckmann 1924; Descoeudres 1921). Most of this early research focused on older preschool children and was concerned with how informal learning and parental training led to a knowledge of counting and related processes, such as the understanding of addition and subtraction.

More recently, research interest has extended to younger children between the ages of 2 and 4. Several studies have revealed that even these younger children demonstrate some knowledge of basic number concepts and are able to estimate the numerosity of arrays smaller than four to five items. This estimation ability, which Descoeudres (1921) has aptly described as the *un, deux, trois, beaucoup* phenomenon is quite robust and has been found to hold in a variety of tasks, such as (*a*) studies of estimation of numerosities (Chi & Klahr 1975; Gelman & Tucker 1975); (*b*) pattern recognition of small numbers of items (Schaeffer, Eggleston, & Scott 1974); and (*c*) number discrimination tasks (Estes & Combes 1966).

These studies have led Gelman and her colleagues (e.g., Gelman 1972; Gelman & Gallistel 1978) to classify number abilities into two categories. First, number abstractors (or estimators) are those processes which enable a child to obtain either an exact or an approximate representation of the numerosity of an array. Second, number reasoning principles (or operators) include those processes which enable a child to define the outcomes of manipulating sets in various ways. The development of number abstraction abilities is assumed to occur ontogenetically prior to and provide the foundation for the development of the ability to use number reasoning principles.

Although this assumption is generally accepted, the specific process or processes involved in the young child's ability to represent numerosity of arrays is a question of current debate. Klahr and Wallace (1976) hypothesize that the development of both counting and estimating abilities is dependent on subitizing, a rapid perceptual process of "immediate apprehension" of the numerosity of an array. Consequently, this suggests that the ability to abstract numerosities is an innate process; the later-developing ability to count requires, in addition, a socially transmitted

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verbal label, noticing of orders, and place keeping. On the other hand, Gelman and her colleagues (Gelman 1972; Gelman & Gallistel 1978; Gelman & Tucker 1975) have presented evidence which supports the conclusion that counting is the "preeminent mechanism" by which young children estimate numbers of all sizes with the possible exception of one and two. They argue that rapid, subvocal counting can explain the results that Klahr and his coworkers use to support their conclusion of the operation of subitizing. Furthermore, if subitizing is involved at all in the number abstraction process, it should be considered a higher-level perceptual process which acts to speed up number abstraction and develops after the ability to count.

Extending the study of the ability to perceive numerosity of arrays to infants would permit more precise conclusions to be drawn about the developmental sequence of and the processes involved in number abilities. Prior to specifying the ontogeny of number abstraction abilities as either primarily perceptual (e.g., Klahr & Wallace 1976) or cognitive (e.g., Gelman & Gallistel 1978), however, it is necessary, first, to demonstrate whether infants are able to discriminate between visual arrays differing only in numerosity, and, second, to ascertain if such discriminations may be affected by factors related to the perception of numerosity—for example, homogeneity of the items.

Thus, a second and related issue is the influence of similarity or uniqueness of items in an array upon estimations of numerosity. Some evidence suggests that heterogeneous arrays (in which each item in the array varies from each other item in qualities such as color, form, or item type) and homogeneous arrays (in which the items are identical) differentially affect the ability to abstract numerosity. Gast (1957) found that preschoolers are able to judge number more accurately when items are homogeneous, rather than heterogeneous. Similarly, Siegel (1973) found fewer numbers of trials to criterion in a numerical equivalence task when the items were homogeneous. These differential effects have been interpreted as evidence of the young child's difficulty in understanding that heterogeneity of items is irrelevant to numerosity. Alternatively, other evidence suggests that preschool children are able to respond to the numerical value of an array, independent of varying nonnumerical properties, such as length and density of array, item type and color, and visual angle (Beckmann 1924; Descoeudres 1921; Gelman & Tucker 1975). In these cases, numerosity seems to be a very salient invariant feature of an array which can be abstracted by young children regardless of homogeneity or heterogeneity of component items.

The adaptation of a multiple habituation paradigm recently used to study the development of perceptual categories in infants (e.g., Caron, Caron, & Carlson 1979; Cohen & Strauss 1979; Strauss 1979) provides a promising method for investigating number abstraction abilities of infants. Typically, an infant is presented with several members of a category until habituation occurs. During a test phase, the infant is presented with two types of instances of the familiar, invariant category (old and new instances) as well as with instances of a new category. The infant's ability to categorize is inferred from his generalization (continued habituation) to new instances of the invariant category and dishabituation to instances from a new category. Recent studies have shown precisely this pattern of results, from which it can be concluded that infants are able to abstract the relevant categorical information which is invariant across stimuli.

As applied to number abstraction, a category would consist of arrangements of an invariant number of items presented with items varying along dimensions of item size and position to control for any effects of density or brightness. If an infant, who had been habituated to a category of a certain number (N), generalizes to a new instance (different item size and position) of the same invariant category and dishabituates to an instance of a novel category (quantity $N + 1$ or $N - 1$), then number abstraction ability could be inferred. Conversely, if the infant generalizes to the new category, then it would be inferred that infants are not capable of abstracting numerosity of arrays.

This technique is also well suited to study the effect of homogeneous/heterogeneous item sets in each category on numerosity estimation abilities. Two conditions were studied. In the first (homogeneous condition) the item type and number remained invariant, while the size and position of the stimuli varied. In the second (heterogeneous condition) only number remained invariant, while item type, size, and position varied. With infants, it could be argued that the heterogeneous condition contains more potentially distracting features (varying item type as well as size and position) and, as a result, may be more difficult. On the other hand, it is known that infants are very skilled at abstracting invariant perceptual information. It could be argued, therefore, that the heterogeneous condition would be easier because the infant's attention is being directly focused toward the only invariant information, that is, numerosity.

The purposes of this study were twofold: (1) To extend the study of abstraction of numerosity of an array to children under 2 years of age in order to determine whether preverbal infants (who cannot be said to count) can distinguish between numerosities of arrays when all variables (e.g., density, brightness) correlated with numerosity are controlled. (2) To determine the effect of homogeneity/heterogeneity of items in an array on infants' perceptions of numerosity.

Method

Subjects.—The subjects were 96 infants (48 males and 48 females) between 10 and 12 months of age ($M = 340$ days, $SD = 44$ days). All infants were healthy, full-term babies with no history of medical or visual problems.

Procedure.—Infants were tested in a single session lasting approximately 15 min. Testing took place in a 1.33 × 2.11-m enclosed space constructed of plywood painted black with a black drape opening. During testing, the room was dark with the exception of three very dim lights mounted on top of the front partition of the enclosed space. The infant sat on his or her parent's lap and was situated approximately 70 cm from the front panel of the enclosed area. A .64-cm peephole in the center of the partition allowed an observer on the other side of the partition to view and record corneal reflections of the stimuli. The stimulus slides were projected on a 30.5-cm square rear-projection glass, the center of which was located 30.5 cm to the right of the observation hole. Located 30.5 cm to the left of the hole was a red, blinking light.

An infant-controlled habituation procedure was employed. All trials began when the infant looked at the blinking light. Upon looking, the blinking light was terminated and simultaneously a stimulus slide was projected. The infant was permitted one unlimited look at the stimulus. When the infant ceased to fixate the stimulus, the slide was terminated and the blinking light turned on to begin the next trial.

All tests were conducted by trained undergraduates, who were naive both to the hypotheses of the study and, in most cases, the experimental condition of a particular infant. The interobserver reliability of recording visual fixations by the use of the corneal reflection technique is quite high. Cohen and Strauss (1979) reported that two independent observers agreed to within 0.5 sec of fixation time on over 98% of the trials.

The experiment consisted of two parts—habituation trials and test trials. During the habituation trials, the infant was shown a series of slides, all of which contained a constant number of items. Upon reaching criterion of habituation (in which the mean fixation time on three consecutive trials was less than 50% of the mean of the first three fixations), the infants received four test trials with two slides containing the same number of items as the habituation series (familiar numerosity) alternated with two slides containing either $N + 1$ or $N - 1$ number of items (novel numerosity). The order in which the infant received the familiar and novel slides was counterbalanced across subjects.

Separate groups of infants were tested on discriminations of 2 versus 3 items, 3 versus 4 items, and 4 versus 5 items. Within each of these conditions, half of the infants were habituated to the lower of the two numerosities (N) and tested with $N + 1$ items (i.e., 2 vs. $2 + 1$, 3 vs. $3 + 1$, and 4 vs. $4 + 1$) and the remainder were habituated to the higher of the two numerosities (N) and tested with $N - 1$ items (i.e., 3 vs. $3 - 1$, 4 vs. $4 - 1$, and 5 vs. $5 - 1$).

Additionally, half of the infants were assigned to a heterogeneous (*He*) condition. During habituation trials, the infants were shown slides in which only the number of items remained invariant, while the item type, size, and position varied from trial to trial. (All items were color drawings of familiar objects from children's books; e.g., chicks, houses, flags, dolls, parrots, dogs, butterflies.) For example, an infant may have been habituated to two large dogs in a particular arrangement on trial 1, two small houses in a different arrangement on trial 2, and so on.

The remaining half of the infants were assigned to a homogeneous (*Ho*) condition in which both the number and type of items remained invariant, while item size and position varied from trial to trial. (The items used for this condition were pictures of chicks.) For example, an infant may have been habituated to three chicks of a particular size and arrangement on trial 1, three chicks of a different size and arrangement on trial 2, and so on.

Stimuli.—In order to ensure that numerosity was the only cue for discrimination and to rule out all other explanations of such discrimination (i.e., density, brightness, contour, area), during habituation the size and position of the items in each array were randomly varied in both experimental conditions. In order to vary position, each of the appropriate number of items was placed randomly upon a 4×4 matrix of possible placements. This resulted in a series of arrays which precluded discrimination on the basis of any simple configurational similarity among the slides. Size was varied in two ways in the *He* condition. First, the items themselves varied in size. Second, in both the *Ho* and *He* conditions, item size was varied by photographing the arrays from one of six randomly determined distances. These manipulations resulted in a wide range of visual angles (2–7 degrees) and controlled for cues correlated with numerosity, that is, density, brightness, area, contour.

During habituation, a set of five different slides was repeatedly shown in the same order until the infant had reached a criterion of habituation. Although it was recognized that, in order to rule out the unlikely possibility of discrimination on the basis of specific pattern learning, it would be advantageous to alter each of the arrays until the infant reached criterion, the decision to use a limited number of different arrays was made to increase the probability of reaching the criterion of habituation. It is important to note that, in both the *He* and *Ho* conditions, since both the familiar (N) and novel ($N + 1$ or $N - 1$) test slides contained items and arrangements which had not been used in the habituation set, the only basis of discrimination would be numerosity. Examples of typical *He* and *Ho* condition tests are presented in table 1.

Results

In order to analyze the results, the infants' total fixations during the two test trials which contained the familiar numerosity were combined and compared with their total fixations during the two test trials which contained the novel numerosity. An initial five-way ANOVA of these looking times was performed. This analysis included the between factors of sex (male vs. female), numerosity (2-3 vs. 3-4 vs. 4-5), condition (*Ho* vs. *He*), and type of discrimination ($N + 1$ vs. $N - 1$) which was nested within numerosity. Trials (familiar vs. novel numerosity) was the single within factor.

This preliminary ANOVA resulted in a reliable four-way interaction among the factors

TABLE 1

EXAMPLES OF TYPICAL *Ho* AND *He* CONDITION PROCEDURES

Example of *He* Condition					Example of *Ho* Condition			
Number	Item	Size	Arrangement		Number	Item	Size	Arrangement	
				Habituation Trials[a]					
2	Dogs	1	1		4	Chicks	6	1	
2	Butterflies	4	2		4	Chicks	4	2	
2	Houses	2	3		4	Chicks	1	3	
2	Dolls	6	4		4	Chicks	5	4	
2	Cats	3	5		4	Chicks	2	5	
2	Dogs	1	1		4	Chicks	6	1	
2	Butterflies	4	2		4	Chicks	4	2	
2	Houses	2	3		4	Chicks	1	3	
2	Dolls	6	4		4	Chicks	5	4	
2	Cats	3	5		4	Chicks	2	5	
				Test Trials					
2	Parrots	2	2	$N + 1$	4	Chicks	5	6	$N - 1$
3	Flags	6	1		3	Chicks	1	7	
2	Parrots	2	2		4	Chicks	5	6	
3	Flags	6	1		3	Chicks	1	7	

[a]Habituation trials were continued until criterion was reached.

of sex, condition, numerosity and trials, $F(2,78) = 3.66$, $p < .03$. This analysis also indicated that there were no reliable effects or trends as a result of type of discrimination ($N + 1$ vs. $N - 1$) and, consequently, these data were combined in all subsequent analyses (e.g., 2-3 and 3-2, 3-4 and 4-3, 4-5 and 5-4).

In order to interpret this four-way interaction, it is helpful to consider the results of the 2-3, 3-4, and 4-5 discriminations separately. Figure 1 illustrates the amount of looking at the familiar and novel test slides in the 2 versus 3 discrimination task. As can be seen, and as verified by one-tailed t-tests which compared familiar versus novel trials, both male and female infants were able to discriminate two-item from three-item arrays. (One-tailed tests were used because differences were predicted in a particular direction, i.e., greater looking on novel trials than familiar trials, a standard finding in the literature.) In addition, this discrimination was made in both the *Ho* and *He* conditions. An ANOVA of this 2-3 numerosity data, which included the factors of sex, condition, and trials, confirmed that there were no significant differences between male and female infants, nor between *He* and *Ho* conditions. As expected, the main effect of familiar versus novel trials was significant, $F(1,28) = 12.78$, $p < .001$.

Figure 2 illustrates the result of the 3 versus 4 discrimination task. In the *Ho* condition, the female infants were able to discriminate numerosity differences while the males were not. Conversely, in the *He* condition, the males were able to discriminate while the females were not. Predictably, an ANOVA of this 3-4 numerosity data indicated that there was a significant three-way interaction among condition, sex, and trials, $F(1,28) = 26.70$, $p < .001$, and a significant main effect of familiar versus novel trials, $F(1,28) = 8.92$, $p < .006$.

Finally, Figure 3 illustrates the results of the 4 versus 5 discrimination task. Neither males nor females demonstrated the ability to make this discrimination in either the *Ho* or *He* conditions. An ANOVA indicated only one significant main effect and no interactions; the infants looked reliably longer at the *He* test stimuli (8.35 sec) than at the *Ho* test stimuli (4.76 sec), $F(1,28) = 4.38$, $p < .05$.

In summary, the analyses reveal that, regardless of condition, infants were able to discriminate between 2 and 3 items and unable to discriminate between 4 and 5 items. For

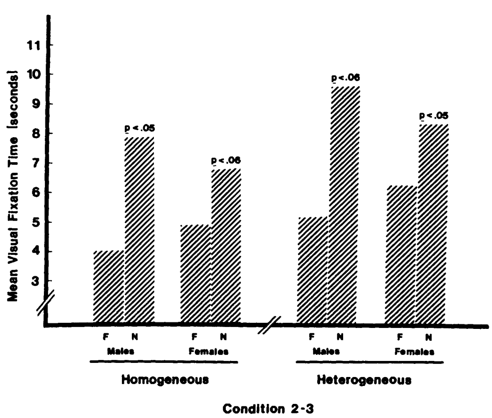

Fig. 1.—Mean visual fixation time of familiar (F) and novel (N) numerosities, condition 2–3.

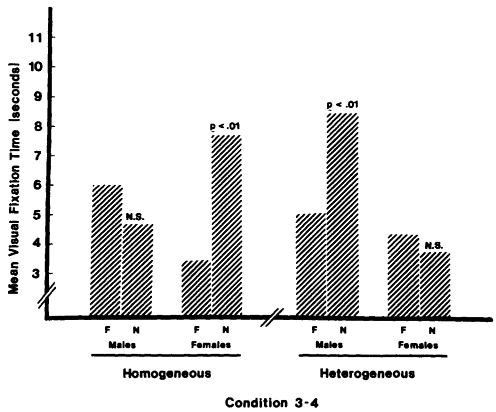

Fig. 2.—Mean visual fixation time of familiar (F) and novel (N) numerosities, condition 3–4.

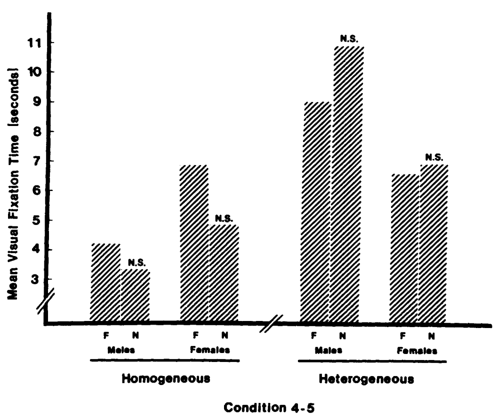

Fig. 3.—Mean visual fixation time of familiar (F) and novel (N) numerosities, condition 4–5.

3 versus 4 items, a sex $\times$ condition interaction was obtained. In order to explain this interaction, a number of different analyses were performed on the habituation data, since it was reasoned that the interaction may have been the result of attentional differences between males and females in the *Ho* versus *He* conditions. An ANOVA of the number of trials to habituation yielded two reliable main effects of sex, $F(1,84) = 4.84$, $p < .03$, and condition, $F(1,84) = 11.61$, $p < .001$, and no reliable interactions. Females required fewer trials ($M = 12.5$) to reach criterion than males ($M = 14.8$). In addition, infants required more trials to habituate in the *He* condition ($M = 15.46$) than in the *Ho* condition ($M = 11.81$). There were, however, no interactions with either sex or numerosity, which would be necessary to clarify the interaction. Analyses of other habituation measures, such as length of fixation on the first three trials ($M = 9.27$ sec) and last three trials ($M = 5.63$ sec) did not yield any reliable differences. Similarly, plotting of both forward and backward habituation curves yielded no obvious explanation for the sex $\times$ condition interaction in the 3-4 discrimination task.

Weak support for possible attentional differences between males and females was provided by the preliminary five-way ANOVA of fixation times during test trials. The analyses yielded a marginally reliable sex $\times$ condition interaction, $F(1,78) = 3.43$, $p < .07$, demonstrating a tendency of males to look longer in the *He* condition (collapsed across familiar and novel test trials) ($M = 16.03$ sec) than in the *Ho* condition ($M = 9.97$ sec). Contrary to expectation, females did not look longer in the *Ho* condition than the *He* condition (*He:* $M = 11.99$ sec; *Ho:* $M = 11.55$ sec). However, if one looks specifically at infants' overall fixations in the 3-4 condition, it can be seen that males look longer at the *He* ($M = 13.39$ sec) than the *Ho* stimuli ($M = 10.65$ sec), and, conversely, females looked longer at the *Ho* ($M = 11.12$ sec) than the *He* stimuli ($M = 8.09$ sec). While this interaction was not reliable, $F(1,28) = 2.13$, $p < .16$, the means do lend support to the idea that the 3-4 interaction may have been the result of differential attention of males versus females to the *He* and *Ho* stimuli.

Discussion

The results of the present study have clearly indicated that preverbal infants can discriminate between small exact quantities and store some type of information related to numerosity. Infants perceived the difference between arrays which contained two and three items even when all perceptual cues other than numerosity were eliminated (e.g., density, brightness, area). The infants were not able to discriminate numerosity when tested with four versus five items.

While the infants also discriminated between arrays of three versus four items, conclusions about this result must be modified in light of the obtained sex $\times$ condition interaction. Although the data suggest no obvious explanation to account for this interaction, it is likely that the three versus four discrimination was more difficult than the two versus three discrimination, and it thus may have placed greater attentional demands on the infants. The interaction could then be explained by hypothesizing that male and female infants were differentially attracted to the *Ho* as opposed to the *He* stimuli. While the infants' overall looking during test trials provided some support for this speculation, there were no obvious differences in the male and female habituation data. However, it must be recognized that habituation indices are overt performance measures which may not directly reflect to what extent the infants are attending to or processing the different visual stimuli.

More importantly, these results demonstrate that some numerosities can be discriminated by infants even though they possess no knowledge of counting. In addition, this ability to discriminate may be affected by differential attentional preferences between homogeneous and heterogeneous arrays of stimuli. It is important to recognize that these results do not necessarily imply that the infant has a cognitive awareness of number and can "represent" numerosity. Two obvious explanations are currently being explored: (*a*) whether this ability to discriminate numerosity is an innate, perceptual skill (e.g., Klahr & Wallace 1976); or (*b*) whether the infant possesses some underlying cognitive awareness of small numbers (e.g., Gelman & Gallistel 1978).

The search for the appropriate explanation can proceed in several different ways. First, one can investigate the application of number perception to other tasks which must involve some degree of cognitive awareness of number, for example, numerosity sequences. Langer (1980) has recently reported that by 1 year of age infants will sort objects into groups of equivalent quantities. Based on videotaped observations of infants' interaction with groups of objects, Langer has also observed what he calls protoaddition and protosubtraction in 6-month-old infants. These infants have been observed to play games where they bang an object once, then twice, and so on, thus demonstrating a numbered sequence. Such experimentation and play by infants might lead to a primitive awareness of number concepts.

Second, the ability to represent numerosity across sensory modalities can be explored. If numerosity can be discriminated auditorily as well as visually, this would point to a more cognitive awareness of number.

Third, the extent to which perceptual features (e.g., pattern arrangement, size, etc.) interact with the ability to discriminate numerosity will help provide an explanation of the development of early number abilities. If the ability to discriminate numerosity were easily affected by alterations of size and/or arrangement, this would implicate a greater role of a perceptual skill.

Thus, the present study represents a significant beginning in the search for the origins of number concepts. Future research will focus on the nature and development of the ability of infants to discriminate numerosity.

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