is some biochemical evidence for such opiate receptor heterogeneity (*16*), although the presence of κ receptors in rat brain has recently been questioned (*17*). The μ receptor is thought to be responsible for the analgesic actions of the opiates and requires the lowest doses of naloxone for reversal. Hence the dose-response curve of naloxone against leucine enkephalin-induced seizures would indicate that some receptor other than the μ receptor is responsible for the epileptogenic action of this substance. The enkephalin-induced electrical seizures and behavioral abnormalities that are overcome by anticonvulsants specific for petit mal indicate possible involvement of enkephalinergic systems in petit mal epilepsy.

O. CARTER SNEAD III
LARRY J. BEARDEN
Department of Pediatrics, Biomedical Engineering, and Neurosciences Program, University of Alabama in Birmingham, School of Medicine, Birmingham 35233

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Perception of Numbers by Human Infants

Abstract. *Infants are capable of discriminating, representing, and remembering particular small numbers of items. A perceptual enumeration process called subitizing, present in 2-year-olds, probably underlies this capacity. This finding indicates that some number capacity is present before the onset of verbal counting, and it suggests that verbal counting may have precursors present during infancy.*

One view of cognitive developmental psychology is that the earliest phases of development must be characterized in terms of capacities as well as incapacities in order to understand the courses (both normal and abnormal) of later development (*1*). Much of the theoretical and empirical research on numerical development has, in the last decade, focused on very young children; we now know that 2- to 4-year-olds understand some basic number concepts (*2*). The presence of numerical abilities in very young children led to the question of the precursors of these abilities, which in turn led us to investigate whether infants have any basic numerical abilities. Our research was motivated by the belief that the ability to represent the numerical value of a set of items may be necessary for the development of an understanding of number. Two-year-olds use a rapid perceptual process (called subitizing) to distinguish among arrays containing fewer than four items (*3*). In this report, we present evidence that 22-week-old infants can also discriminate exact numbers of items. This raises the possibility that the young child's verbal counting abilities grow in part from the infant's numerical ability.

The focus of our study was to demonstrate skills for perceiving and representing specific small numbers of items. This focus differs from that of experiments demonstrating the ability of infants to discriminate stimulus arrays that greatly differ in number (such as 2 versus 8 versus 32 versus 128 items) (*4*). These discriminations treat numbers of items that massively exceed the range of those adults and children can subitize, since the adult subitizing range is one to four or five items (*5*). The bases of discriminations among large values are not known and may vary with different types of arrays (for example, dot size, the spatial distance separating adjacent dots, or surface area of the total array). The ability underlying these discriminations might be the same as that which allows adults to estimate the more numerous of two arrays differing substantially in number; however, such skills are clearly different from subitizing, and they cannot provide the same kind of information for later number development as the perception and representation of exact small numerical values.

Our experimental method used duration of first fixation in a standard habituation- dishabituation-of-looking procedure (*6*). The subjects were 72 normal, full-term infants with a mean age of 22 weeks (range, 16 to 30 weeks). The infants were first habituated to arrays containing a particular number of dots and were then presented a posthabituation (PH) array containing a different number of dots (Fig. 1). The small-number conditions ($2 \rightarrow 3$ and $3 \rightarrow 2$) were chosen because 2-year-olds can perceive and store the number of items of 2- and 3-dot arrays (*3*); both $2 \rightarrow 3$ and $3 \rightarrow 2$ were used because infants might prefer complexity. The large-number conditions ($4 \rightarrow 6$ and $6 \rightarrow 4$) were chosen as controls because 2-year-olds can not perceive (that is, subitize) arrays containing four or more dots (*3*). Since 4:6 maintains the same ratio as 2:3, large-number conditions to some extent control for discrimination based on physical cues such as differences in total contour.

We analyzed the data several ways, and each analysis revealed the same pattern of results: dishabituation occurred when the number of items was small but

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Table 1. Means and standard deviations of looking times (in seconds) during habituation (H) and posthabituation (PH) trials.

Condition	Final three H trials	First three PH trials	Statistical comparisons* d.f.	t	P	d.f.	t	P	Final H trial	First PH trial	Statistical comparisons* d.f.	t	P	d.f.	t	P
2 → 3	2.09 ± 0.53	2.53 ± 1.15	17	2.08	<.06	35	3.46	<.005	1.93 ± 0.67	2.54 ± 1.36	17	2.46	<.03	35	3.71	<.001
3 → 2	2.03 ± 0.67	2.83 ± 1.65	17	2.77	<.02				1.70 ± 0.64	2.44 ± 1.45	17	2.71	<.02			
4 → 6	2.69 ± 0.95	2.58 ± 0.87	17	0.48	>.50	35	0.66	>.50	2.33 ± 0.94	2.40 ± 1.09	17	0.29	>.50	35	1.40	>.15
6 → 4	2.48 ± 0.79	2.42 ± 0.77	17	0.46	>.50				2.08 ± 0.62	2.46 ± 0.76	17	1.86	>.08			

*The same significance patterns were obtained for log-transformed looking times.

not when it was large (Table 1). We also compared looking time on the final presentation of particular habituation arrays (H1 and H2) with mean looking time on the first three PH trials. Significant dishabituation was revealed in both small-number conditions but not in the large-number conditions. The infants also discriminated among small arrays that were identical in length but not number (H1 versus PH in the 2 → 3 condition and H2 versus PH in 3 → 2) and in density but not number (H2 versus PH in 2 → 3 and H1 versus PH in 3 → 2). These discriminations did not occur in the large-number conditions.

A number of potential explanations for these findings can be ruled out. The discrimination of small arrays can not be based on the length, density, or dot positions of the PH arrays, because (i) the same value of these cues appeared in at least 50 percent of the H trials and (ii) the infants discriminated between small arrays that were identical in length but not number and in density but not number. Complexity preference also cannot be responsible for the results since dishabituation occurred in both small-number conditions.

It is unlikely that the infants' discrimination was based on brightness or contour-density differences between the H and PH arrays, because discrimination should also have occurred for the large-number conditions in which these differences were larger. Also, adults cannot discriminate those brightness differences, and infants are apparently no more sensitive than adults (*7*). Thus, we conclude that the change in number per se was the basis for dishabituation when the arrays had few items; dishabituation did not occur in the large-number conditions because infants can not perceive the particular absolute number of an array of more than two or three items (*8*).

We think it likely that subitizing underlies the infants' performance in the small-number conditions. The basis for our position is the presence of subitizing in children (*3*, *9*), the rapidity and numerical range of the enumeration process used by the infants, and the unlikelihood that infants can count verbally or that two independent processes for establishing exact small numbers would have evolved (*10*). However, even if we were to conclude that a subitizing phenomenon had been observed in infants, we would still know little about its component processes (for example, whether iteration or template-matching takes place or whether the same iteration process is used in verbal counting and in subitizing—as a primitive form of counting). Also, the component processes may change with age (infants may represent a two-object array as "a thing and a thing," whereas young children represent it as "two things"). Further work is needed on problems such as the nature of infant number abilities, the nature and early development of subitizing, its link (if any) to verbal counting, and whether subitizing serves as a psychological foundation of the number system.

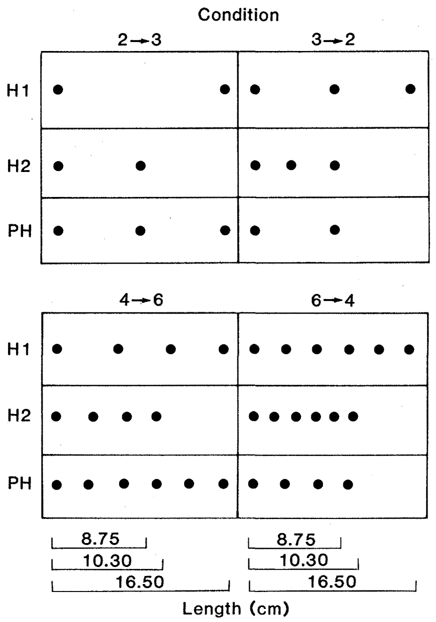

Fig. 1. Representation of stimuli. Abbreviations: *H1* and *H2*, habituation arrays; *PH*, posthabituation arrays. Dots were 1 cm in diameter; luminance of the dots was 280 mL and of the 20-cm by 30-cm screen, 2.4 mL. Infants were approximately 60 cm from the screen. In each condition, the two habituation arrays contained the same number of dots but differed in length and density; the posthabituation array contained a different number of dots but the same length as one habituation array and the same density as the other. Habituation arrays were presented in random orders. In each condition (except 4 → 6), the location of each dot in the posthabituation array was identical to the location of a dot in a habituation array. The distance between any pair of adjacent dots was equal to the distance between any other pair of adjacent dots in the same array. Thus, the stimuli were constructed to avoid discrimination by dot spacing or configurational cues such as triangularity (*11*).

PRENTICE STARKEY
Department of Psychology,
University of Pennsylvania,
Philadelphia 19104

ROBERT G. COOPER, JR.
Southwest Educational Development
Laboratory, Austin, Texas 78708

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dishabituated to a three-dot array having the same density as the six-dot array (R. G. Cooper, P. Starkey, J. Dannemiller, in preparation). In two other experiments (P. Starkey, E. Spelke, R. Gelman, in preparation) infants discriminated three- versus four-dot arrays and two- versus three-object arrays when slides of heterogeneous arrays of common household objects rather than dots were used as stimuli. This study is important since total contour varied considerably from slide to slide.

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Associative Learning in Premature Hydranencephalic and Normal Twins

Abstract. *A hydranencephalic infant lacking cerebral hemispheres and a normal twin were tested for associative learning. After repeated trials in which two stimuli were temporally paired, test trials were given in which the second stimulus was omitted. Cardiac orienting responses to stimulus omission indicated that learning had taken place in both infants.*

Continued research into the neural mechanisms of behavior has greatly expanded our appreciation of the capacity of lower brain structures to subserve many complex behavioral processes—processes which historically have been considered to be the domain of the cerebral hemispheres. Decerebrated animals retain a vast array of behavioral functions, including the capacities for habituation and learning (*1*). The breadth of the capability of brainstem mechanisms has recently been punctuated by Norman *et al.* (*2*), who demonstrated a classically conditioned eyelid response in cats with upper brainstem transections and further documented discriminative conditioning between auditory stimuli in the same animals. In addition, Huston and Borbely (*3*) have provided evidence of operant conditioning in the decerebrated rat, using brain stimulation as the reinforcer.

As impressive as these data may be, their implications concerning the functional organization of the human brainstem are clouded by the fact that the behavioral capacity of animals with upper brainstem transections diminishes dramatically with the increasing phylogenetic level of the organism (*1*). The tragic conditions of anencephaly and hydranencephaly in the human infant, which are characterized by the absence of the cerebral hemispheres, provide human clinical parallels to the animal brainstem preparation. Although generally short-lived, anencephalic and hydranencephalic infants retain many vegetative and reflexive capacities of the normal neonate (*4, 5*). Consonant with the experimental findings in animals, accumulating reports on hydranencephalic and anencephalic infants tend to confirm the retention of habituation processes (*4, 6*). The capacity of these infants to develop learned associations, however, has not, to our knowledge, been documented. In order to further examine the learning capabilities of subcortical networks in the human, we tested for associative learning in a premature twin pair, one member of which was hydranencephalic, the other apparently normal. We here report evidence of stimulus-stimulus association in both infants.

The subjects were dizygotic twins, one male and one female, born 2 months prematurely at an estimated gestational age of 32 weeks. The male showed no clinical abnormality, but examination of the female revealed widespread transillumination of the skull and hyperactive Moro and deep tendon reflexes. Air encephalography confirmed the tentative diagnosis of hydranencephaly, a condition of variable etiology in which the cerebral hemispheres are replaced by a thin meningeal and ependymal membrane (*7*). The air study (Fig. 1) revealed the virtual absence of the cerebral hemispheres. These findings were further confirmed by computerized axial tomography, which also revealed grossly abnormal basal ganglia and dorsal thalami.

The learning capability of the infants was evaluated through tests for the development of conditioned associations between two simple stimuli. Ethical considerations precluded the use of the strong stimuli typical of conditioning studies; therefore, we used an adaptation of the perceptual disparity procedure (*8*) to evaluate stimulus-stimulus association through the establishment of stimulus "expectancy." Two innocuous stimuli were paired in close temporal contiguity and repeatedly presented to the subject.

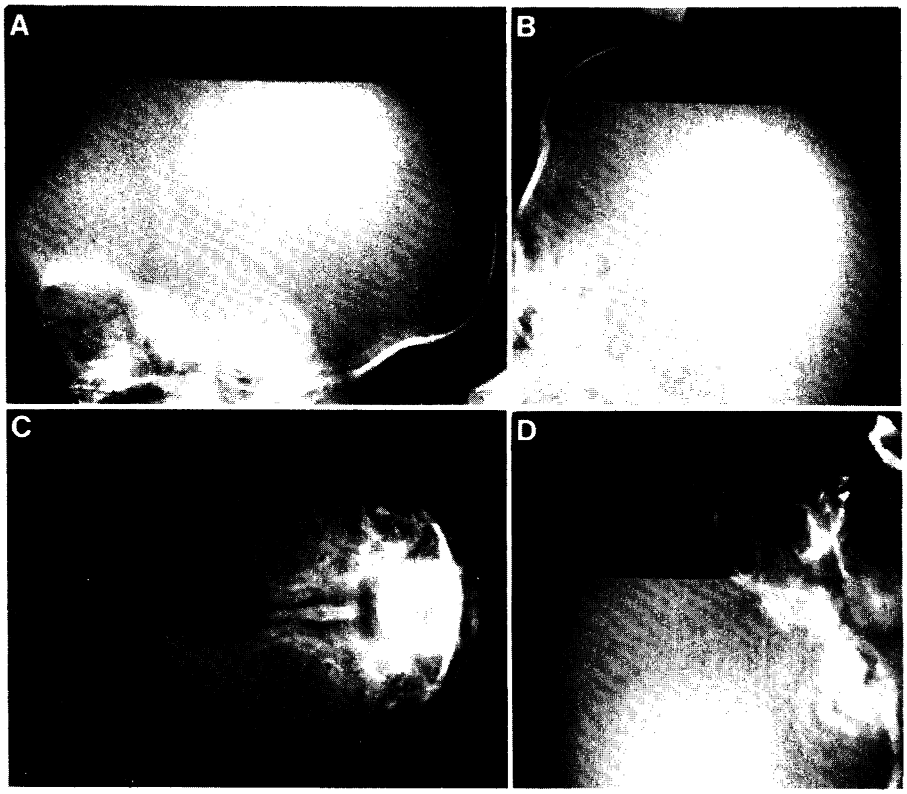

Fig. 1. Pneumonencephalograms demonstrating the condition of hydranencephaly in the female infant. (A) Upright lateral view; note dorsal locus of air in the cranial cavity. (B) Brow down lateral view. (C) Left side down view. (D) Brow up view.

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