Perception of Numerical Invariance in Neonates

Sue Ellen Antell and Daniel P. Keating
University of Maryland Baltimore County

ANTELL, SUE ELLEN, and KEATING, DANIEL P *Perception of Numerical Invariance in Neonates* CHILD DEVELOPMENT, 1983, **54**, 695–701 40 healthy, normal newborn infants were evaluated with reference to their ability to discriminate among visual stimulus arrays consisting of 2 versus 3 or 4 versus 6 black dots Infants made this discrimination within a habituation/dishabituation paradigm for the small number sets (2 to 3 and 3 to 2) but not for the larger sets (4 to 6 and 6 to 4) We argue that this suggests the ability to abstract numerical invariance from small-set visual arrays and may be evidence for complex information processing during the first week of life

Research into neonatal cognitive processing has traditionally consisted of the investigation of elementary processing and the elucidation of techniques whereby such mechanisms may be objectively quantified (Fantz, 1963, 1965, Friedman, 1972b) Another, more recent line of work (e g , Brazelton, 1973) has investigated basic issues in neurological integration, organization, and state functions in very young infants Such work has provoked a reconceptualization of infants as active, organized information processors rather than passive and disorganized sensory receptors The research in which we are engaged takes this as its starting point and examines newborns to gain some understanding of the "rules" by which information may be processed Gibson (1969) has argued that cognitive development consists in part of the ability to abstract the invariant features in a changing environment and, in this way, to organize experience In this research, we attempted to extend this principle downward to examine whether the neonate enters the world with significant components of such abstraction To investigate this possibility, we selected the numerosity problem presented to 4-month-old infants by Starkey and Cooper (1980) In that experiment, the infants were tested for their ability to abstract a small-set numerical invariance from simple stimulus arrays The investigation of numeric competency in preschool children has revealed the presence of numeric discrimination prior to the adoption of a "mature" form of the counting system (Gelman, 1972, Gelman & Galistel, 1978) Starkey, Spelke, and Gelman (Note 1) suggest that number may represent a "natural domain of competence," and suggest that similar processes may underlie the ability of 4-month-old infants to make simple numeric discriminations If this is indeed the case, then it is not unreasonable to suspect that even very young infants may be able to demonstrate similar abilities under well-controlled conditions

Although it was previously assumed that visual acuity in the newborn is too poor to allow for any reliable assessment of complex visual information processing, recent research has established that acuity in the newborn is at least 20/150 (Dayton, Jones, & Aui, 1964) Harris and Macfarlane (1974) demonstrated the principle of active peripheral vision and identified the visual field of the neonate as an angle of at least 25 from the center of fixation to the periphery

Friedman and his colleagues (Friedman, 1972a, 1972b, Friedman, Bruno, & Vietze, 1974, Friedman & Carpenter, 1971, Friedman, Nagy, & Carpenter, 1970) conducted a number of studies designed to explore in detail the habituation of visual fixation in neonates They found, as predicted, that attention declined over trials but in-

This research was partially supported by the Graduate Student Research Award from the Maryland Psychological Association to the first author Computer time was donated by the University of Maryland Baltimore County We thank Albert Caron and Rose Caron for their encouragement and helpful comments We also thank Jacob Felix and Kathleen Stevens, neonatologist in charge of the newborn nurseries at Sinai Hospital of Baltimore, Cindy Ziegler, head nurse, newborn nursery, and the nursery staff for their assistance and cooperation during this project Research assistants for the project were Lisa Schneider and Nilima Bhatt Requests for reprints may be sent to either author at the Department of Psychology, University of Maryland Baltimore County, Catonsville, Maryland 21228

[*Child Development* 1983 **54**, 695–701 0009-3920/83/5403-0009$01 00]

creased significantly when novelty was introduced Such work demonstrated clearly that visual habituation is not attributable to generalized oculamotor fatigue and could be used as a measure of differential response to stimulus

Neonates thus probably do possess some primitive "memory" capacity, the ability to detect stimuli presented to the periphery and actively orient toward it, and the ability and inclination to search the environment for visually interesting stimuli, but this still fails to provide any substantive evidence of processing higher than the level of sensory systems by which information may be organized

The research described here provides initial evidence for such organizational processes It begins with the hypothesis that cognitive development is a continuous process, and that precursors of later abilities can be identified even in neonates when performance factors are carefully controlled We use the habituation/recovery technique of observing infant attention as an index of complex processing By controlling the stimuli so that dishabituation is tied to the discrimination of novelty in a previously invariant feature, we have been able to assess directly such a function in infants during the first week of life

Method

Subjects—Subjects for this research were 40 normal, healthy newborn infants ranging from 21 to 144 hours old ($M = 53$ hours) who were in residence in the newborn nursery at Sinai Hospital in Baltimore Infants included in the study met the following minimum criteria weight greater than 2,720 grams, Caesarean section for maternal cause only, Apgar scores at least 8/9, estimated gestational age not less than 38 weeks, no evidence of fetal distress during labor, obstetrical medication consisting of regional anesthesia only, 50 mg demerol or equivalent, or no medication, no obvious neonatal abnormality or illness, bilirubin less than 7 mg on day 1, 10 mg on day 2, and 12 mg thereafter, infants not undergoing phototherapy, no chronic or gestational illness in mother, male infants tested prior to circumcision Consents were obtained from the parent of an additional 25 normal infants, but these additional subjects were dropped from the study for failure to attain or maintain the desired state (quiet alert) long enough for the full procedure Infants were tested within 1 hour of the next scheduled feeding, typically in the late afternoon

Stimuli—The stimulus materials consisted of eight 15 × 15-cm white cards upon which were printed a discrete number (2, 3, 4, or 6) of black dots of 8 cm diameter Each habituation array contained two stimulus cards with the same number of dots but which varied in terms of the length of the line or the density between the dots The posthabituation array in each stimulus condition consisted of a card which contained a novel number of dots (2 to 3, 3 to 2, 4 to 6, or 6 to 4), but which maintained the line length of one of the habituation arrays and the dot density of the other (see Figure 1) During exposure, the stimulus cards were inserted into a white bracket affixed to a white foamboard screen that had been cut to fit the side of the hospital bassinet This screen shielded the infant from all nonexperimental visual stimuli as long as he or she remained visually oriented in the direction of the target

Procedure—After parental consents were obtained, the investigator checked the selected subjects for state Any infant who was found spontaneously in the quiet alert state was tested immediately Infants who were awake but crying were settled into the appropriate state prior to testing Infants who were found to be asleep at the time of testing were gently awakened and the desired state induced if possible Once in the quiet alert state, infants were placed on their left sides in their own hospital bassinet, at an optimal distance of approximately 17–19 cm from the screen (Haynes, White, & Held, 1965) Infants who were very active and needed restraining were swaddled, pacifiers were also used by all subjects

Although pacifiers have been found to decrease the amount of visual scanning in young infants (Bruner, 1973), they have been

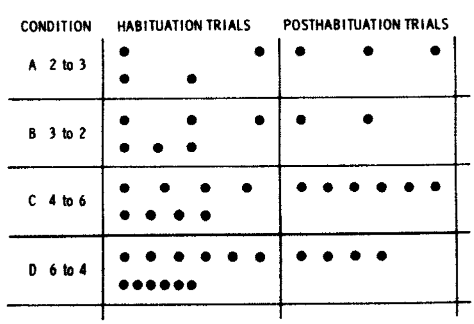

FIG 1 —Simulus array for conditions 1–4

found to be useful in maintaining concentration and orientation to the stimulus (Bruner, 1973, Haith, 1980, Mendelson & Haith, 1975) Additionally, nonnutritive sucking is considered by some (Bower, 1967, Bruner, 1973) to be a reliable index of visual discrimination Infants were then manually oriented toward the screen and the first habituation target was displayed During the procedure, the investigator stood behind the infant with her right hand lightly touching the pacifier (so that it would not be lost during testing) and her left hand resting on the infant's abdomen This physical contact was used to maintain a quiet alert state The investigator maintained a very light and constant pressure on all infants in all conditions, regardless of whether they appeared to be attending to the stimulus

Each trial began when the observer (who was unaware of the experimental condition and the criterion of habituation), standing to the left of and above the infant's head (out of the line of vision), adjudged the infant to be looking at the target A trial continued for a maximum of 40 sec, or until the observer judged the infant to be visually off target for 2 or more sec Off-target behaviors included closing of eyes, turning head or body away from the target, crying, or falling asleep If an infant fell asleep during the trial, the trial was concluded, but if he or she could be alerted again within the 10-sec intertrial interval, testing continued In practice, some infants did doze slightly between trials, but would alert fully upon stimulation Those infants ($N = 25$) who could not be again alerted were dropped from the study for failure to maintain state

During the habituation phase, the infant received exposure alternately to two stimulus cards containing the same number of dots but varying in length of line and density between the dots They continued receiving exposure to these same two cards until they reached a preset criterion of habituation two consecutive trials in which there had been a minimum decrement of 8 sec from the mean looking time recorded for the first two trials This habituation criterion is the one described by Friedman (1972a, 1972b) as having the greatest empirical utility In terms of this research, the mean decrease in looking time was 56%, but the criterion was an absolute rather than a percentage value After reaching criterion, the infants were exposed to the third card in the condition, which represented a test of perception of numerosity This new card contained a novel number of dots but maintained the line length of one of the habituation arrays and the dot density of the other Infants received two trials with the test stimulus

Recording of time of visual fixation was accomplished manually by either of two trained research assistants with a Casio digital stopwatch with readout to 01 sec Pearson correlation coefficients computed on looking time as recorded by the two observers during three sessions of testing for interrater reliability were 99, 995, and 995 for each of the 3 individual days and 952 over the three testing sessions (total observation time = 58 2 min, total number of trials = 126) Male and female infants were randomly assigned to each of the four stimulus conditions so that each condition cell contained five male and five female infants

Results

The design for the experiment consisted of a 4 (condition) × 2 (gender) × 2 (habituation/posthabituation) mixed analysis of variance (ANOVA), with the first two factors between subjects and the last within subjects The dependent variables were mean times of visual fixation for the last two habituation trials and the first two posthabituation trials, respectively In order to obtain results more comparable with those reported by Starkey and Cooper (1980), we also compared the times obtained on the last habituation trial with those obtained on the first test trial by means of simple t tests

Additional data analyses consisted of two 2 (condition) × 2 (gender) ANOVAs in which the dependent variables were trials to criterion and total time of visual fixation during habituation, respectively Correlational analyses of obstetrical factors (obtained from infants' medical charts) with trials to criterion and with sum of habituation time were also conducted

Results of the primary data analysis revealed a significant main effect for habituation/dishabituation, $F(1,32) = 31\ 57$, $p < 001$, indicating that overall, infants looked more during the two test trials than they did during the last two habituation trials The crucial habituation × condition interaction was also significant, $F(3,32) = 5\ 81$, $p < 003$ The increase in looking time was substantial in the two small-number conditions (2 to 3 and 3 to 2, with an average increase of 102% and 67%, respectively) in contrast to the two large-number conditions

(4 to 6 and 6 to 4, with an average increase of 13% and 16%, respectively) We further confirmed the interaction in an analysis of the last habituation and first posthabituation trial only, using a series of pooled-variance t tests The obtained t's by condition were 3 88, $p <$ 001 (2 to 3), 3 01, $p <$ 05 (3 to 2), 82, N S (4 to 6), and 29, N S (6 to 4) The means and standard deviations of the last two and first two trials are shown in Table 1 These results form essentially the same pattern reported by Starkey and Cooper (1980) for 4-month-old infants and suggest that the ability to abstract numerical invariance in small sets is present in human newborns

The only other significant result was the habituation × gender interaction, $F(1,32) =$ 4 50, $p <$ 05, indicating that change in looking time between habituation and test arrays for male infants was greater than for female infants males had a mean looking time of 14 85 sec for the last two habituation trials and a mean of 25 42 for the two test trials across all conditions, females had a mean of 15 85 sec and 20 62 sec This difference could not be attributed to any obvious obstetrical factors and needs to be evaluated in light of research into gender effects on habituation (Tighe & Powlison, 1978, Antell, Note 2)

The two additional ANOVAs yielded no significant main effects or interactions, indicating that neither gender nor condition had an effect upon either trials to criterion or total looking time during habituation

Finally, the correlational analysis revealed no significant relationships between the use of anesthesia, analgesia, length of second stage, method of feeding, age of infant, or use of pitocin with either the sum of the habituation time or with the number of trials to criterion, with the exception of a just significant correlation ($r =$ 31, $p <$ 05) between the use of regional anesthesia and the sum of habituation time, in the direction that those infants whose mothers had received regional anesthesia had marginally longer looking times

This result is interesting in light of research that suggests that visual information processing in infants may be affected by maternal medication (Bowes, Brackbill, Conway, & Steinschneider, 1970, Stechler, 1964) There was, however, no evidence in our data to suggest a medication effect on discrimination, but rather only on total length of looking during habituation

Discussion

Previous research using the habituation paradigm has been used to identify important parameters of newborn visual preference (Fantz, 1963, 1965, Friedman, 1972a, 1972b, Friedman, Carpenter, & Nagy, 1970, Friedman et al , 1970, Hershenson, 1964) In this research we capitalized upon those earlier findings and used the same paradigm to demonstrate the ability of neonates to detect numerical difference in arrays consisting of small numbers of discrete stimuli, an ability that breaks down when the set becomes too large This is the same pattern of results obtained by Starkey and his colleagues with older infants (Starkey & Cooper, 1980, Starkey et al , Note 1, Starkey & Cooper, Note 3) using essentially the same methodology In the Starkey and Cooper (1980) experiment, as well as our own, the infants were exposed to an invariant feature (numerosity) within arrays that varied two other dimensions (length and density) At test, only the numerosity varied, which suggests that infants made the discrimination by abstracting the numerical invariance and recognizing

TABLE 1

Means and Standard Deviations of Last Two Habituation and First Two Posthabituation Trials, by Condition (in Seconds)

Condition	Last Two Habituation Trials: Mean	Last Two Habituation Trials: SD	First Two Posthabituation Trials: Mean	First Two Posthabituation Trials: SD
2 to 3	15 3	5 6	30 8	9 1
3 to 2	15 9	7 6	26 6	6 6
4 to 6	14 9	5 9	16 9	9 2
6 to 4	15 3	9 8	17 8	4 7

the novel numerosity as different The fact that they could not make this discrimination in the two large-number conditions suggests that they were not merely responding to a change in contour density, and later research by Starkey et al (Note 1), in which novel objects instead of dots were used to provide a number of changes in contour density during both habituation and test, argues even more forcefully for this conclusion We would presume that essentially the same principle is operative in our own research, especially in view of the lack of discrimination in the large-number conditions, although further research is needed to confirm this assumption

Although the evidence from this study supports the general notion of the ability of newborn infants to abstract invariant features in a stimulus array, the presence of additional redundant cues (such as background brightness, background area, and total target area) leaves open the possibility that the infants were abstracting an invariant other than number, despite the fact that they were apparently unable to extract any such information (including number) in the large-number conditions While we think it implausible that it was these cues, rather than number cues, that enabled the infants to discriminate the arrays, further research is needed in which such extraneous cues are controlled before final conclusions regarding numeric competence can be drawn

Additional evidence for an information-processing interpretation of the data comes from an evaluation of the mean looking times for the first two habituation arrays in each condition The means obtained were 33 06, 33 698, 34 99, and 33 625 for the first two trials in the 2 to 3, 3 to 2, 4 to 6, and 6 to 4 conditions, respectively This indicates that infants had no prior preference for any of the stimuli and so could not be discriminating merely on the basis of some "pre-wired" response mechanism (such as seems to operate in color discrimination) It further suggests some processing that requires an active organizational ability on the part of the subjects In this paper, we have advanced the theoretical notion that newborn infants may begin this process of organization by tuning into the invariant stimulus features in the surround

Similar techniques have been used extensively to document the ability of older (2 or more months) infants to abstract stimulus invariants from arrays that varied along a number of dimensions Caron, Caron, and Carlson (1979) and McGurk (1972) found that infants were able to discriminate an invariant shape across changes in color, size, and orientation, and further to generalize habituation to a novel instance of the redundant property Others have demonstrated the capacity of infants to abstract color across changes in wavelength (Bornstein, Kessen, & Weiskopf, 1976) and object rigidity across movement transformations (Gibson, Owsley, & Johnston, 1978)

Investigators have also examined the ability of infants to abstract information regarding the nature of the relations between stimulus components and have demonstrated the ability to do so across changes in shape, density, and orientation (Caron & Caron, 1980, Cornell, 1975, Milewski, 1979, Ruff, 1976, Schwartz & Day, 1979) That the foregoing process may represent a kind of primitive category construction has been posited by a number of authors (Caron & Caron, 1982, Cohen & Strauss, 1979) as an explanation of cognitive development in older infants

It is important in this context to note that the ability to abstract invariant stimulus features and the discrimination of novelty based on such abstraction does not imply an understanding of the features by the infant or the ability at this stage to integrate the information in a meaningful way What it does suggest is that the rules whereby information is extracted may be similar throughout infancy, and this is important for both practical and epistemological reasons to researchers in the cognitive development of infancy

Numerosity is but one example of the kinds of information that may be accessible to neonates Additional research needs to be done to determine the range of such abilities Our research demonstrates that by using simple procedures that do not require the infant to deal with too much unnecessary information, evidence for such processes may be obtained

Reference Notes

1 Starkey, P , Spelke, E , & Gelman, R *Number competence in infants Sensitivity to numeric invariance and numeric change* Paper presented at the International Conference on Infant Studies, New Haven, Conn , April 1980

2 Antell, S *Sex differences in habituation research* Unpublished manuscript, 1981

3 Starkey, P , & Cooper, R *Number develop-*

ment *Numerosity perception in infants* Mimeographed Final report, National Institute of Mental Health grant no RO1MH31895

References

Bornstein, M , Kessen, W , & Weiskopf, S Color vision and hue categorization in young human infants *Journal of Experimental Psychology Human Perception and Performance*, 1976, **2,** 115–129

Bower, T G The development of object permanence Some studies of object constancy *Perceptual Psychophysics*, 1967, **2,** 411–418

Bowes, W A , Brackbill, Y , Conway, E , & Steinschneider, A The effects of obstetrical medication on fetus and infant *Monographs of the Society for Research in Child Development*, 1970, **35**(4, Serial No 137)

Brazelton, T B *Neonatal behavioral assessment scale* Philadelphia Heinemann, 1973

Bruner, J Pacifier produced visual buffering in human infants *Developmental Psychobiology*, 1973, **19,** 434–439

Caron, A , & Caron, R Processing of relational information as an index of infant risk In S L Friedman & M Sigman (Eds), *Preterm birth and psychological development* New York Academic Press, 1980

Caron, A , & Caron, R Cognitive development in early infancy In T Field, A Huston, H Quay, L Troll, & G Finley (Eds), *Review of human development* New York Wiley, 1982

Caron, A , Caron, R , & Carlson, V Infant perception of the invariant shape of an object varying in slant *Child Development*, 1979, **50,** 716–721

Cohen, L , & Strauss, M Concept acquisition in the human infant *Child Development*, 1979, **50,** 419–424

Cornell, E H Infants' visual attention to pattern arrangement and orientation *Child Development*, 1975, **46,** 229–232

Dayton, G , Jones, M , Aui, P Developmental study of coordinated eye movement in the human infant I Visual activity in newborn humans A study based on induced optokinetic nystagmus recorded by electrooculography *Archives of Ophthalmology*, 1964, **71,** 865

Fantz, R Pattern vision in newborn infants *Science*, 1963, **140,** 296–297

Fantz, R Visual perception from birth as shown by pattern selectivity *Annals of the New York Academy of Sciences*, 1965, **118,** 793–814

Friedman, S Newborn visual attention to repeated exposure of redundant vs "novel" targets *Perception and Psychophysics*, 1972, **12,** 291–292 (a)

Friedman, S Habituation and recovery of visual response in the alert human newborn *Journal of Experimental Child Psychology*, 1972, **13,** 339–349 (b)

Friedman, S , Bruno, L , Vietze, P Newborn habituation to visual stimuli A sex difference in novelty detection *Journal of Experimental Child Psychology*, 1974, **18,** 242–251

Friedman, S , & Carpenter, G Visual response decrement as a function of age of human newborn *Child Development*, 1971, **42,** 1967–1971

Friedman, S , Carpenter, G , & Nagy, A Decrement and recovery of response to visual stimuli in the newborn human *Proceedings of the American Psychological Association*, 1970, **5,** 273–274

Friedman, S , Nagy, A , & Carpenter, G Newborn attention Differential response decrement to visual stimuli *Journal of Experimental Child Psychology*, 1970, **10,** 44–51

Gelman, R Early number concepts In H W Reese (Ed), *Advances in child development and behavior* (Vol 7) New York Academic Press, 1972

Gelman, R , & Galistel, C R *The child's understanding of number* London Harvard University Press, 1978

Gibson, E J *Principles of perceptual learning and development* New York Appleton-Century-Crofts, 1969

Gibson, E J , Owsley, C J , & Johnston, J Perception of invariants by five-month old infants Differentiation of two types of motion *Developmental Psychology*, 1978, **14,** 407–415

Haith, M *Rules that babies look by* Hillsdale, N J Earlbaum, 1980

Harris, P , & Macfarlane, A The growth of the effective visual field from birth to seven weeks *Journal of Experimental Child Psychology*, 1974, **18,** 340–348

Haynes, H , White, B L , & Held, R Visual accommodation in human infants *Science*, 1965, **148,** 528–530

Hershenson, M Visual discrimination in the human newborn *Journal of Comparative and Physiological Psychology*, 1964, **56,** 270–276

McGurk, H Infant discrimination of orientation *Journal of Experimental Child Psychology*, 1972, **14,** 151–164

Mendelson, M , & Haith, M , The relation between nonnutritive sucking and visual information processing in the human newborn *Child Development*, 1975, **46,** 1025–1029

Milewski, A Visual discrimination and detection of configural invariance in 3-month infants *Developmental Psychology*, 1979, **15**, 357–363

Ruff, H Developmental changes in the infant's attention to pattern detail *Perceptual and Motor Skills*, 1976, **43**, 351–358

Schwartz, M , & Day, R. Visual shape perception in early infancy *Monographs of the Society for Research in Child Development*, 1979, **44**(7, Serial No 182)

Starkey, P , & Cooper, R Perception of numbers by human infants *Science*, 1980, **210**, 1033–1034

Stechler, G Newborn attention as affected by medication during labor *Science*, 1964, **144**, 315–317

Tighe, T , & Powlison, L Sex differences in infant habituation research A survey and some hypotheses *Bulletin of the Psychonomic Society*, 1978, **12**, 337–340