Developmental Psychology
1999, Vol. 35, No. 3, 640–650

0012-1649/99/$3.00

Feeding-Based Arousal Effects on Visual Recognition Memory in Early Infancy

Ronny Geva, Judith M. Gardner, and Bernard Z. Karmel
New York State Institute for Basic Research in Developmental Disabilities

Arousal effects on a 1-trial visual recognition paired-comparison task were studied at newborn, 1-month, and 4-month test ages. Infants were tested before and after feeding, with arousal assumed to be lower after feeding. Newborns and 1-month-olds shifted from a familiarity preference before feeding to a novelty preference after feeding. A control group tested only after feeding confirmed that this shift was not due to increased stimulus exposure from the prefeeding test. By 4 months, infants showed novelty preferences independent of feeding. This age by arousal interaction for recognition memory extends previous knowledge by including endogenous arousal with age, stimulus, and length of exposure as contributors to familiarity–novelty preferences. It also extends and provides converging evidence for arousal effects on visual attention in early infancy found previously with preferential looking. A shift from subcortical to cortical dominance is supported.

The visual recognition memory testing procedure is used for studying information processing and cognitive abilities in nonverbal populations, as is the case when studying human infants. Typically, the method involves presenting two identical visual stimuli for a fixed amount of time. After this familiarization period, one of the familiarized stimuli is replaced with a novel one so the infant can view simultaneously both the familiar and novel stimuli. On the basis of the tendency to attend to novel events, infants are expected to prefer a new stimulus when it is paired with a previously viewed familiar stimulus. An underlying assumption in such a paradigm is that the infant is processing information in short-term memory rather than merely responding on the basis of immediate sensory stimulation.

This type of information processing in infants has been found to follow a specific sequence (Hunter, Ames, & Koopman, 1983; Rose, Gottfried, Melloy-Carminar, & Bridger, 1982). Initially, as the infant becomes familiar with a stimulus, to the extent that he or she can recognize it when it is presented along with a new stimulus, a preference for the familiar stimulus is argued to indicate continued encoding. Once the familiar stimulus becomes sufficiently encoded, however, the infant can now not only detect but also encode new information and thus begins to exhibit a novelty preference. The age of the infant, the nature of the stimulus, and the amount of time presented for familiarization are all important aspects in determining whether an infant will show a familiarity or a novelty preference. If an infant is younger, the stimulus is more complex (i.e., more difficult to process), or the amount of time allowed for processing is too short, the infant will continue to process and encode the familiar stimulus and show a familiarity rather than a novelty preference. Therefore, most studies of visual recognition memory manipulate the amount of time allowed for familiarization as well as the complexity of the stimulus to enhance the probability of obtaining novelty preferences at different ages. Initially, it was believed that younger infants show familiarity preferences whereas older infants show novelty preferences (Friedman, 1972). This belief was based on findings that infants younger than 2 months showed familiarity preferences regardless of the stimulus as presentation trials progressed (Fantz, 1964), whereas by 4 months, they showed novelty preferences, especially if they had longer periods in which to become familiar with the stimulus (Rose et al., 1982). However, with extended familiarity times, even preterm and 1-month-old infants exhibited novelty preferences when alterations in sucking patterns were used as the dependent measure (Milewski & Siqueland, 1975; Werner & Siqueland, 1978). Subsequently, this shift to novelty preferences after longer familiarization was confirmed when looking behavior was used as the dependent measure, with longer familiarization necessary the younger the infant (Rose et al., 1982; Slater, Mori-

---

Ronny Geva, Judith M. Gardner, and Bernard Z. Karmel, Department of Infant Development, New York State Institute for Basic Research in Developmental Disabilities, Staten Island, New York.

Ronny Geva is now at the Child Development Center and Neuropediatric Unit, Tel-Aviv Medical Center, Tel Aviv, Israel.

Portions of these data were presented at the biennial meeting of the Society for Research in Child Development, March 1993, New Orleans, Louisiana.

This research was supported in part by National Institute of Child Health and Human Development Grant HD-21784, National Institute of Drug Abuse Grant DA-06644, and funds from the New York State Office of Mental Retardation and Developmental Disabilities.

We express our gratitude and appreciation to the medical and nursery staffs of the Neonatal Intensive Care Unit and Newborn Nursery of the Sisters of Charity Medical Center, St. Vincent's Campus, Staten Island, New York, for their cooperation. We are indebted to Robert L. Freedland for his advice with regard to the study's design, to David J. Lewkowicz for sharing his knowledge and for his thoughtful editing of the article, to Ivy Feldman for her general helpfulness and editing, and to Catherine L. Magnano for her overall encouragement. We thank Elise Conway, Amy Del Rosario, Bonnie Ferrando, Sylvia Gregg, and Lazinka Smith for their assistance with participant recruitment and data collection.

Correspondence concerning this article should be addressed to Judith M. Gardner, Department of Infant Development, New York State Institute for Basic Research in Developmental Disabilities, 1050 Forest Hill Road, Staten Island, New York 10314. Electronic mail may be sent to jmgsi@cunyvm.cuny.edu.

son, & Rose, 1982, 1983). Thus, familiarity preferences and novelty preferences appear to reflect different stages of information processing by the infant, but both provide evidence for some form of short-term stimulus experience on subsequent behavior.

In the typical visual recognition memory study, state of arousal is assumed to be constant. As long as the infant is awake and attending, he or she is assumed to be in the same state and therefore processing at the same level. Although this assumption may be accurate for older infants, it may not be appropriate for infants during the neonatal period, when responsivity to and processing of stimulation may be at different levels and subject to different internal controls. Gardner and colleagues have argued that for neonates, arousal and attention work interdependently as a self-organized autoregulatory system that combines internal (endogenous) and external (exogenous) stimulation to specify systematic directional shifts in attention to particular stimuli (Gardner & Karmel, 1983; Gardner, Karmel, & Magnano, 1992; Karmel, Gardner, & Magnano, 1991; Turkewitz, Gardner, & Lewkowicz, 1984; Turkewitz, Lewkowicz, & Gardner, 1983; see also Zeskind & Marshall, 1991). When more aroused, normal neonates prefer less stimulation, and when less aroused, they prefer more stimulation. This arousal-modulated attention effect has been verified in a series of studies demonstrating systematic shifts in visual preferences toward slower temporal frequencies (slower rates of change) or lower spatial frequencies (less dense contour per unit area) in stationary patterns when neonates were (a) endogenously more aroused (before feeding) as opposed to less aroused (after feeding; Gardner & Karmel, 1984, 1995; Gardner et al., 1992; Gardner & Turkewitz, 1982; Karmel & Gardner, 1996) and (b) exogenously more aroused due to increased amounts of pre- or concurrent stimulation within or between modalities (Gardner & Karmel, 1995; Gardner et al., 1992; Gardner, Lewkowicz, Rose, & Karmel, 1986; Karmel & Gardner, 1996; Lewkowicz & Turkewitz, 1981). That feeding affected endogenous arousal was verified by using heart rate (Gardner & Turkewitz, 1982), with the finding that basal heart rate was higher before than after feeding. That amount of stimulus energy affected exogenous arousal was evidenced by a general increase in heart rate throughout stimulus presence when infants were presented with higher stimulus energy (i.e., faster temporal frequencies) than with lower stimulus energy (i.e., slower temporal frequencies; Gardner & Dowd, 1983). It is not known whether such arousal effects influence performance rather than just attention to the stimulus on a task that has been assumed to reflect memory and cognitive processing, such as visual recognition memory. Slater (1995) indicated that the optimal time for testing neonates on such tasks is immediately after feeding and that infants tested midfeeding fall asleep or give unreliable responses. If arousal modulation affects this behavior, lack of reliability with midfeeding testing could be due to an arousal effect from either partial satiation or some infants being satiated and some not. Immediately before feeding, infants would show differential responding in opposite ways to those found immediately after feeding, rather than unreliable responses.

Although it is possible that arousal might affect performance on the visual recognition memory task during the neonatal period, it is less likely that it might affect the performance of older infants. By 2–3 months of age, infants gain more control over their internal and external worlds and are less influenced by their internal arousal state when arousal is modulated as described above (Gardner & Karmel, 1995; Karmel, Gardner, & Freedland, 1996). They become capable of inhibiting their responses to internal stimulation and modulate their attention primarily depending on specific characteristics of the external environment by reacting to particular stimulus features as a function of experience and stimulus configuration (Karmel, 1969; Karmel & Maisel, 1975; Maurer & Lewis, 1979; Woodruff, 1978). For example, in infants younger than but not older than 2 months, changing the brightness or the size of a stimulus can alter contour density and pattern preferences (Maisel & Karmel, 1978; McCarvill & Karmel, 1976; Ruff & Turkewitz, 1975, 1979). Shifts in face recognition also appear to occur at about 2 months of age (see Johnson & Morton, 1991; Lewis et al., 1998; Maurer, 1985). This developmental shift to higher order sensory-specific determinants of visual behavior has been hypothesized to relate to the influence of emergent cortical development on subcortical mechanisms controlling early attention (see Braddick & Atkinson, 1988; Bronson, 1974; Gardner & Karmel, 1983; Johnson, 1990, 1996; Karmel et al., 1991; Maurer & Lewis, 1979; Morton & Johnson, 1991; Turkewitz et al., 1983, 1984; Woodruff, 1978). However, this shift in the organization of attentional systems is not without controversy. Some investigators argue that preferences in newborns are a function of stimulus energy whereas preferences after about 2 months of age appear to be more influenced by stimulus structure (Kleiner, 1993; Kleiner & Banks, 1987) or a shift from subcortical CONSPEC mechanisms to a cortical CONLERN mechanism (Morton & Johnson, 1991); others maintain that stimulus energy or intensity remains a factor even at 4 months, depending on the situation and the characteristics of the stimulus (e.g., Kaplan, Fox, Scheuneman, & Jenkins, 1991; Kaplan & Werner, 1991; Lewkowicz, 1985a, 1985b); and still others contend that newborns function on the same basis as older infants but that the problem is in devising ways of tapping into their capabilities (Bower, 1989).

The primary purpose of the present study was to investigate developmental changes in the effects of arousal modulation on visual recognition memory responses in early infancy. If there are developmental shifts that occur after the newborn period and they are similar to those demonstrated for visual preferences, we would expect infants at 1 month to behave similarly to neonates (because 1 month is still considered to be within the neonatal period) whereas infants at 4 months should show some newer level of performance. That is, if the studies showing a lack of arousal modulation on stimulus intensity effects after 2–3 months of age are relevant (whether because of emerging predominance of cortical rather than subcortical mechanisms or some other developmental change in visual functioning), we would predict that by this age, arousal modulation effects would no longer interact with performance on visual recognition memory in a manner similar to its having limited influence on visual preferences. Therefore, we hypothesized that increasing or decreasing endogenous arousal, for example, by testing infants before or after feeding, should not affect novelty preferences after 2–3 months of age, whereas a similar manipulation of arousal should affect novelty preferences in infants younger than this age, maintaining the exogenous stimuli constant across age.

We chose to use a feeding-based endogenous manipulation of arousal in the present study. It was easier to manipulate feeding than exogenous stimulation effects without confounding the familiarity–novelty characteristics of the test situation while at the same time maintaining as much consistency across conditions except for experimenter manipulation. In addition, our previous experience indicated that the most effective exogenous stimulation when used to manipulate arousal was in the same modality and fairly intense. We were concerned that we could not introduce such intense visual stimulation before familiarization without influencing the processing of the stimulus, and we could not present such stimulation after familiarization without destroying the familiarization effect itself.

Moreover, the present design allowed us to evaluate any other unplanned but nonrandom effects of our arousal manipulation. That is, if feeding affected visual recognition memory through mechanisms other than arousal (despite the previously found shifts in heart rate before and after feeding; Gardner & Turkewitz, 1982), we should obtain differences in other aspects of the infants' behavior, such as amount of accumulated time necessary for reaching criteria. For instance, we could investigate whether any differences in novelty preferences that occurred with the feeding manipulation were due to infants being more fidgety and therefore not processing as well. In that case, they should take longer to accumulate looking time without necessarily looking at familiar and novel stimuli differentially. In contrast, if amount of accumulated looking affected familiarity versus novelty preferences, then infants who looked for shorter amounts of time should tend to show more familiarity. However, if there were no differences in accumulated looking but differences in familiarity versus novelty, then those differences likely would be due to some other factor, for instance, arousal modulation in the present study.

A secondary purpose of this study was to explore during early development the feasibility of using a one-trial procedure to evaluate visual recognition memory. Typically, experimenters (i.e., Fagan, 1984; Fagan & Singer, 1983; Rose, 1988) have assumed that repeated trials are needed to correctly characterize infants' novelty responses. However, averaging novelty scores over trials may not add to the reliability or the validity of the results obtained with young infants because novelty cannot be assumed to be constant across trials over time. For instance, overall levels of stimulation and fatigue, rather than task-specific familiarity–novelty parameters, may dominate the infants' performance, especially at younger ages. Thus, experience over trials within a test session would suggest a different response to stimulation on the first as opposed to the last trial of a series. Indeed, the internal consistency of infant novelty preferences as measured by item-to-item correlation typically is low (.20 to .25; Benasich & Bejar, 1992; Cohen & Gelber, 1975; Colombo, Mitchell, & Horowitz, 1988; Fagan, 1984; Rose, Feldman, Wallace, & McCarton, 1988; Woroby, 1986). With the exception of Slater and his colleagues (see Slater & Morison, 1991), consistent preferences in infants under 2 months of age have been difficult to demonstrate, and even 4-month-olds have been found to complete fewer visual recognition memory tasks than originally expected (Colombo et al., 1988; Richards, 1988). Thus, the design of this study involved using a one-trial procedure in which we administered a single test trial (with right–left position reversed for half of the trial) following a familiarization period both before and after feeding.

Method

Participants

Data are reported from 227 normal healthy infants who participated as part of a low-risk cohort in a larger longitudinal follow-up study of various prenatal and neonatal risk conditions. Infants were excluded who had chromosomal or congenital abnormalities, identified neurological problems, or any indication of prenatal exposure to illicit drugs or alcohol as determined by maternal report or urine or meconium toxicology. All infants were at least 36 weeks of gestational age (Ballard, Novak, & Driver, 1979) and weighed at least 2,250 g at birth, with their mean birth weight being 3,257 g ($SD = 551$). All had 5-min Apgar scores greater than 6. They were tested at postterm ages adjusted for any degree of prematurity, with mean corrected ages at test of 40.0 weeks ($SD = 1.7$) for newborns, 44.9 weeks ($SD = 1.6$) at 1 month, and 58.5 weeks ($SD = 1.3$) at 4 months. Boys accounted for 42% of the infants, and girls accounted for 58% of the infants. The ethnic distribution was 35% Caucasian, 44% Black, 17% Hispanic, and 4% Indian, Near East, and Asian. Eighty-five infants (37%) were initially assigned to the neonatal intensive care unit (NICU). Normal central nervous system status was confirmed during the newborn period by brain-stem auditory evoked responses and, in some cases, by cranial ultrasonography (Gardner, Karmel, Magnano, Norton, & Brown, 1990; Karmel, Gardner, Zappulla, Magnano, & Brown, 1988). Infants in the main study group ($n = 209$) were tested longitudinally at 1 and 4 months of age, with an additional 18 infants composing an independent control group tested only after feeding at 1 month. Thirty-five of the infants tested at 1 and 4 months also were tested as newborns. There was no infant attrition on this task at any age.

Arousal Level Conditions

Arousal manipulations were similar to those used previously (Gardner & Karmel, 1984; Gardner et al., 1992; Gardner & Turkewitz, 1982), with infants considered more aroused before feeding and less aroused after feeding. We and others have verified this supposition by using both behavioral and psychophysiological measures to evaluate endogenous changes due to feeding and swaddling conditions (see Gardner & Karmel, 1983, and Karmel et al., 1991, for more complete explanations; see also Chisholm, 1978; Giacoman, 1971; Korner, 1972; Lipton, Steinschneider, & Richmond, 1965; Pomerleau-Malcuit & Clifton, 1973). Moreover, neonates have been reported to be in an optimal state for testing immediately after feeding (Slater, 1995), and they remain the longest in a quiet, alert state (lying still, eyes open and scanning, stable posture, and regular respiration) at this time (Casaer & Eggermont, 1985).

For the 35 infants tested as newborns, the procedure was performed in a separate quiet room in either the full-term nursery or the NICU. Feeding schedules and amount consumed were dictated by hospital protocol. In this particular hospital, newborns were fed approximately every 4 hr and were expected to consume between 45 and 60 cc. Infants in the NICU ($n = 8$) were fed by the experimenters, whereas infants in the full-term nursery ($n = 27$) typically were fed by their mothers. Although there was more control over the test situation for the NICU infants, the full-term nursery infants might have been considered healthier. In any case, these 35 infants represented a subset of the infants in the study, all of whom were born at or near term and were considered healthy by medical staff. They showed no differences in their data on the basis of which nursery they were in or compared with their 1-month data. Thus, any differences in initial care or test circumstance did not appear to affect their novelty preferences.

For 1- and 4-month visits, infants were brought to the laboratory 15–30 min before their anticipated feeding time. If they were asleep on arrival, they were allowed to wake up slowly at their caregivers' discretion. They were tested before feeding, and then they were fed to satiation by their caregivers, after which they were tested again. Because infants at these ages may or may not be on a schedule and may eat different amounts, we relied on the caregivers to supply information as to the feeding status (i.e., to inform us that the infants were ready to eat or were now full). We could not ethically dictate that the infants must consume a certain number of ounces of formula. The only stipulations were that it be at least 2.5 hr after a previous feeding and that the infants drink at least 2 oz (this was verifiable because fewer than 5% of the infants were nursed). Any other procedures performed during the same visit, such as the neonatal neurobehavioral evaluation (Gardner et al., 1990) or the Bayley Scales of Infant Development (Bayley, 1969, 1993), were administered subsequent to the postfeeding condition.

Stimuli and Apparatus

We tested the infants in the one-trial visual recognition memory task using the black-and-white sunburst and diamond patterns from Rose (1980; see Figure 1). We chose these stimuli even though they were not equated for stimulus energy (e.g., contour density) because they had been used previously by Fagan (1984) and by Rose (1988) and because we could test for any differences in effect even after counterbalancing presentation across infants and conditions. The stimuli were 18 cm^2, with inner edges 10 cm apart. The testing apparatus consisted of a three-sided gray chamber. Stimuli were mounted on a back panel that rotated to permit stimulus changes with minimal delay. Stimulus changes from familiarization to test trials and left–right alternation within test trials took less than 2 s. A centrally located 0.5-cm peephole allowed an unobtrusive observation of the infants' direction of gaze by an observer whose on-line button presses were detected by a computer program that also controlled trial duration and stored all data to disk.

Procedure

An infant-controlled familiarization procedure was used for accumulation of predetermined familiarization durations of 30 s, 20 s, and 10 s at newborn, 1-month, and 4-month test ages, respectively.[1] Initial familiarization stimulus and initial position of the novel stimulus during the testing phase were counterbalanced within infants and randomized across infants to control for stimulus saliency or visual field lateralized preferences. Test trials were fixed at 20 s, with left–right position reversed after 10 s at all three ages.

The infant was held in a semireclining position on the parent's or a tester's lap, facing the back panel, about 25 cm from the presented stimuli. Testing began when the infant was in a calm and alert state as soon as the infant first looked at the stimuli. During each trial, an observer looked through a peephole and judged the direction and the duration of gaze fixation to each stimulus of the pair. Interobserver reliability with this technique typically is greater than .95. After the initial prefeeding test, the infant was fed and then was retested with the same procedure for the postfeeding test, with the other stimulus of the pair being familiarized and the novel item presented first on the side opposite to the one used in the prefeeding condition.

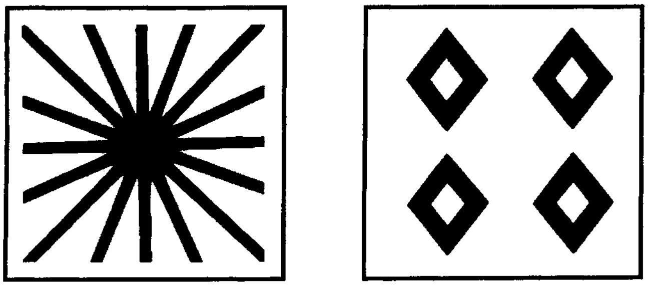

Figure 1. The sunburst and diamond stimulus patterns that were presented. From "Enhancing Visual Recognition Memory in Preterm Infants" by S. A. Rose, 1980, *Developmental Psychology, 16,* p. 87. Copyright 1980 by the American Psychological Association. Reprinted with permission.

The two conditions were administered around the same feeding. Counterbalancing test order (i.e., postfeeding followed by prefeeding) was not practical on follow-up visits because that would have required the young infants and their caregivers to stay in the laboratory an unreasonable length of time over two feeding sessions. A previous study of neonates using a visual preference task in which order of feeding condition was counterbalanced across infants yielded no test order effect (Gardner et al., 1992). The independent control group tested only after feeding at 1 month served to evaluate the effect of test order in the present study.

The dependent variables analyzed were the accumulated time each infant took to become familiarized with the stimuli (i.e., total time to reach familiarization criterion) as well as the total amount of time the infant looked at the novel and familiar stimuli during the test phase across both left and right presentations. A novelty score was derived by calculating the percentage of time the infant spent looking at the novel stimulus relative to the total amount of time spent looking at both stimuli.

Results

The effect of arousal level across age on visual recognition memory performance was evaluated for data from 209 infants by using a 2 (age at test) × 2 (arousal condition) within-subjects multivariate analysis of variance at 1 and 4 months of the prefeeding versus postfeeding novelty scores. This overall analysis indicated that the percentage of time spent looking at the novel stimulus significantly interacted with both age at test and arousal condition, $F(1, 208) = 104.65, p < .000001$. The main effects of age, $F(1, 208) = 6.52, p < .02$, and arousal, $F(1, 208) = 149.09$, $p < .000001$, also were significant. The interaction was due to a significant arousal effect at 1 month that was not evident at 4 months of age. At 1 month, infants preferred the familiar stimulus before feeding (mean % novelty = 32) and the novel stimulus after feeding (mean % novelty = 69). At 4 months, infants preferred the novel stimulus both before and after feeding (53% and 55% novelty, respectively). Not all infants were tested as newborns because it was not possible to institute visual recognition memory testing in the hospital at the beginning of the study. Analysis of the subset of the aforementioned infants who also were tested as newborns ($n = 35$) showed the same arousal effect at the newborn test age as seen at 1 month. Newborns preferred the familiar stimulus before feeding (31% novelty) and the novel stimulus after feeding (70% novelty). Comparison of the data from these infants tested as newborns and again at 1 month indicated the behavior was similar; novelty scores did not differ as a function of age, $F(1, 34) = 0.16$, or the Age × Arousal interaction, $F(1, 34) = 0.30$. Thus, at both the newborn and 1-month test ages, but not at 4 months (similar to what was shown previously for looking preferences; Gardner & Karmel, 1995), feeding-based arousal modu-

---

[1] Pilot studies with an independent sample of 18 four-month-old infants indicated that 15 s of accumulated time was sufficient for them to show reliable novelty responses at about 57% both before and after feeding. However, because part of our rationale in the pilot studies was ultimately to be able to find an accumulated familiarization time that would allow the infants enough time to process the information but yet would be short enough to elicit an arousal effect if still present, we reduced the criterion for 4-month-olds in the present study to 10 s.

lation differentially affected visual recognition memory, with familiarity preferred when infants were more aroused and novelty preferred when infants were less aroused (see Figure 2).

Because the infants were presented with a two-choice forced situation, novelty preferences in each arousal condition at each age were tested for differences from a 50% chance level. This was accomplished by subtracting a constant (0.5) from each novelty proportion and testing whether the residual was significantly different from zero by using a one-way *t* test for each condition at each age. The results indicated all were significantly different from chance but in opposite directions at the newborn and 1-month test ages and in the same direction at 4 months of age. The findings for the newborn test age were as follows: before feeding, $t(34) = -4.05$, $p < .000001$; after feeding, $t(34) = 4.09$, $p < .000001$. The findings for the 1-month test age were as follows: before feeding, $t(208) = -9.84$, $p < .000001$; after feeding, $t(208) = 10.21$, $p < .000001$. The findings for the 4-month test age were as follows: before feeding, $t(208) = 2.24$, $p < .03$; after feeding, $t(208) = 3.77$, $p < .003$. These findings were characteristic of the population rather than of a few infants showing extreme scores. Table 1 shows the number of infants with familiarity (<50%) and novelty (>50%) scores in each condition at each age. Eight infants at exactly 50% were excluded: 7 at 1 month (3 before and 4 after feeding) and 1 at 4 months (before feeding). All chi-square analyses were significant (see Table 1) and remained so even when we added the excluded infants into the analyses in the less preferred direction.

Due to the experimental design, visual recognition memory scores in the different arousal conditions could have been confounded by test order because the first test was always the higher arousal condition (before feeding). To investigate this possibility, we tested a comparable control group of 18 one-month-olds only once, in the postfeeding condition. Because looking at the familiar stimulus when the infants were more aroused before feeding was the outcome of the initial test and looking at the novel stimulus when the infants were less aroused was the outcome of the repeated test, looking at the novel stimulus when the infants were less aroused after feeding on an initial test would rule out order of testing as an alternative explanation for the arousal by novelty preference interaction. Thus, testing only postfeeding would rule out the possibility that this shift was due to increased preexposure experience rather than to arousal level. Indeed, these control infants showed a strong postfeeding novelty preference of 75% that was not different from that obtained postfeeding for the main group (69%), $F(1, 225) = 0.84$, indicating the significant postfeeding novelty preference was not due to having been previously tested before feeding.

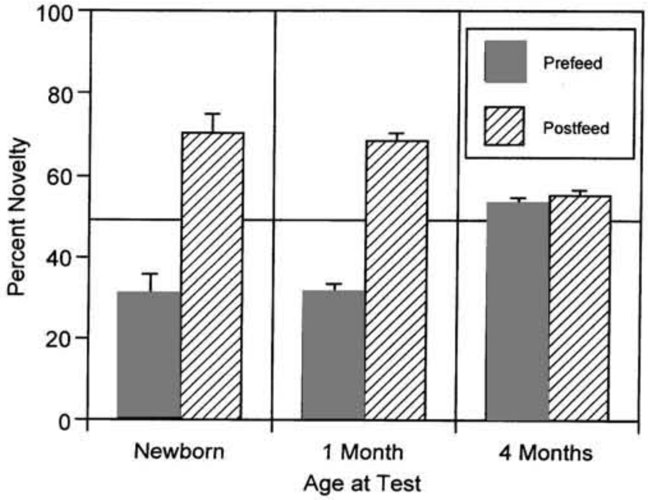

Figure 2. The percentage of time looking at the novel stimulus for infants when more and less aroused at newborn, 1-month, and 4-month test ages. Vertical lines depict standard errors of the means.

The amount of time taken to accumulate the respective familiarization criteria and the amount of time spent looking during the test trials at each age in each arousal condition are shown in Table 2. Note that looking times during familiarization represented total time taken to accumulate 30, 20, and 10 s of looking at the familiarization stimuli, whereas looking times during the test trials were the total looking to both the familiar and novel stimuli during the 20-s trial presentation. Although infants at each age took slightly longer before than after feeding to reach familiarization criteria (0.7, 0.7, and 0.9 s at newborn, 1 month, and 4 months, respectively), none of these differences across arousal conditions reached significance, $Fs < 1.00$. Thus, it is unlikely that any of the novelty preferences or interactions with arousal condition were due to test condition effects (e.g., adjusting to the room or the test situation) or to infants showing inadequate attention before feeding from being too fidgety or upset or after feeding from being too sleepy. A difference was found, however, for the amount of time infants looked during the test trials in the different arousal conditions at 1 month, $F(1, 196) = 12.55$, $p < .0005$, and 4 months, $F(1, 196) = 6.53$, $p < .02$. As can be seen in Table 2, this difference was due to a 1-s increase in average looking after than before feeding. Analyses were performed to determine whether such a difference could affect familiarity–novelty preferences. In no condition at any age was there any relationship between the amount of time spent looking during the trial and familiarity or novelty preferences.

Furthermore, none of the novelty preferences or interactions with arousal condition or age were due to variables that estimated the infants' degree of maturation at birth (i.e., birth weight or gestational age), gender, or whether the infants were initially in the full-term nursery or the NICU. Regression analyses using models with these potentially confounding variables yielded no significant main or interaction effects, $Fs < 1.50$.

Familiarization stimulus was randomized across infants. Still, the effect of familiarization stimulus on novelty preferences was tested to rule out possible saliency differences between the sunburst and diamond patterns. The analysis showed that the particular stimulus used for familiarization did not affect novelty preferences at newborn and 1-month tests, $Fs < 1.00$. At 4 months, there also was no effect of familiarization stimulus on novelty preferences before feeding, $F < 1.50$. However, an effect was seen after feeding, $F(1, 207) = 6.01$, $p < .02$, with infants familiarized with diamonds showing stronger novelty preferences to the sunburst pattern than vice versa. This appears to be due to a stimulus effect at this age in this condition because there was no difference in amount of time it took to reach criterion. It suggests in our data that stimulus saliency may have affected novelty preferences (as reported by others for older infants, e.g., Caron, Caron,

Table 1
Number of Infants Preferring Familiarity and Novelty in Each Arousal Condition at Each Age

	Prefeeding			Postfeeding		
Age	Familiarity (<50%)	Novelty (>50%)	$\chi^2(1)$	Familiarity (<50%)	Novelty (>50%)	$\chi^2(1)$
Newborn	27	8	10.31**	7	28	12.60***
1 month	156	50[a]	54.54****	41	164[b]	73.80****
4 months	89	119[c]	4.33*	67	142	26.91****

Note. Infants at exactly 50% were excluded from analysis.
[a] Three infants were excluded. [b] Four infants were excluded. [c] One infant was excluded.
$*p < .05$. $**p < .005$. $***p < .0005$. $****p < .0000002$.

Minichiello, Weiss, & Friedman, 1977; Colombo, O'Brien, Mitchell, & Horowitz, 1986; Kaplan et al., 1991; Mundy, 1984; Saayman, Ames, & Moffett, 1964) but was too weak an effect to counter any influence of endogenous arousal on familiarity–novelty preferences of younger infants during the neonatal period.

Discussion

The present study provides information about the nature of developmental effects on visual recognition in healthy infants during the first 4 months of life. We investigated the effects of feeding-based arousal modulation on a one-trial recognition memory task and found an interaction of arousal with novelty preferences that changed between 1 and 4 months. Results indicate that both newborn and 1-month-old infants strongly preferred the familiar stimulus before feeding and the novel stimulus after feeding. The use of a control group at 1 month showed that the preference for the novel stimulus after feeding was stable and independent of whether there had been additional exposure to the stimulus before feeding. Neonates were capable of processing higher levels of information by demonstrating novelty preferences only when they were less internally aroused (after feeding). In contrast, at 4 months, infants' novelty preferences appeared independent of feeding-based arousal level. By this age, significant novelty scores were obtained both before and after feeding, with no difference between conditions but some indication that stimulus saliency could affect performance.

The present finding of increased processing capability under lower arousal is consistent with other studies of visual attention showing greater preference for more intense stimulation after feeding during the neonatal period (see Gardner & Karmel, 1983; Karmel et al., 1991). Thus, in recognition memory, as in visual preferences, at younger ages, arousal and attention appear to work interdependently as a self-organized regulatory system that combines internal and external stimulation into some optimal level that specifies attention in a systematic way. The findings also are consistent with previous findings showing differences in behavior emerging after the neonatal period (at about 2 to 3 months), with no increment in the transition within the neonatal period (between newborn and 1 month of age). This suggests that a significant shift in the mechanisms governing attentional responsiveness takes place during this time and that feeding-based arousal modulation plays a significant role in the neonatal period but not by 4 months of age.

The effects of the arousing properties of the stimulus also may be different at different points in development. When the task is fairly easy (i.e., discriminable stimuli, sufficient time to process), increased arousal from a novel stimulus (along with stimulus saliency) may serve to prime and focus an older infant's attention, enhancing the tendency to seek novelty. Indeed, Richards (1997) recently showed that even with shorter familiarization times, the likelihood of a novelty preference after focused or sustained attention is activated or increases. Kaplan et al. (1991) also showed that 4-month-old infants displayed facilitative effects on visual attention (dishabituation) as a result of increased stimulus energy from a particular stimulus producing optimal changes in arousal. In contrast to the effects of an arousing stimulus for older infants, increased stimulus energy could more easily produce arousal overload and have a detrimental effect on neonates' responsiveness by requiring them to devote more energy to process the same stimulus, especially when internal arousal is increased before feeding.

The present findings suggest that the patterns of arousal–attention integration and their change over development correspond to a common neurodevelopmentally based process across tasks. An explanation of the neural mechanisms mediating the

Table 2
Total Looking (in Seconds) Across Age and Arousal Condition During Familiarization and Test Trials

	Familiarization period			Test trials	
Age	Criterion	Prefeeding	Postfeeding	Prefeeding	Postfeeding
Newborn	30	40.2	39.5	15.4	16.0
1 month	20	23.4	22.7	16.8	17.8
4 months	10	16.1	15.2	14.2	15.2

activating properties of stimulation in neonates was hypothesized previously (Gardner & Karmel, 1983; Karmel et al., 1991). The fact that now visual recognition memory can be shown to be strongly influenced by arousal suggests that aspects of the central nervous system that respond to stimulation are shared with those that process information and are involved in memory as well as attention. We have speculated that central nervous system mechanisms mediating arousal-modulated attention likely involve at least the actions of the reticular formation on other subcortical regions controlling visual behavior during the neonatal period (Bronson, 1974, 1982; Gardner & Karmel, 1983; Hoffmann, 1978; Karmel et al., 1991; Karmel & Maisel, 1975; Maisel & Karmel, 1978; McCarvill & Karmel, 1976; Salapatek, 1975; Turkewitz et al., 1983, 1984; Woodruff, 1978). These mechanisms might include reticular–mesencephalic projections of the specific and nonspecific tracts of the sensory systems as well as the lateral geniculate, superior colliculus, pretectum, and limbic system. Reduced cortico–fugal inhibitory influences over lower brain regions (Gerrity & Woodruff, 1979; Lindsley & Wicke, 1974; McGraw, 1943) probably contribute to the effect. That is, when neonates were in a more aroused condition prior to feeding, stimulation from both specific and nonspecific sources impinging on the reticular formation, without concomitant inhibitory influences from other regions, could have produced high levels of neural activity that were self-sustaining. When feeding reduced the amount of endogenous stimulation or made it more organized, the overall level of neural activity could have been decreased or at least made more coherent (Anokhin & Shuleikina, 1977; Kukorelli & Juhasz, 1977). As a result, attention resulted in looking to more stimulation or, as in the case here, to novel stimuli.[2]

We further speculate that the development of cortical functions modifies these early basic subcortical influences of arousal on attention to generate the type of behavioral differentiation observed in older infants. Karmel and Maisel (1975) suggested that at least one emergent cortical process may be reflected by the rapid growth in sensory-specific systems after about 2 months of age, as is the case for vision (Ellingson, 1967). Whether a different system is needed for memory or whether memory is embedded in the total system that processes the sensory information remains to be demonstrated. Our data suggest that such speculation is relevant not only for basic visual attention based on stimulus energy but also for behavior typically thought to be based on higher level information processing requiring short-term memory. More recent discussions (see Atkinson & Hood, 1997; Johnson, 1990) support more specific means by which initial subcortical systems controlling visual behavior may be superseded by or integrated with developing cortical mechanisms but are difficult to generalize outside the visual system to include arousal modulation or the effects of concurrent stimulation from other modalities. Rothbart and colleagues (see Rothbart, Ziaie, & O'Boyle, 1992) have attempted this by proposing mechanisms to explain the influence of stress and overarousal on some of these processes, at least for older infants.

The interaction with arousal found at younger ages appears to support the view that visual recognition behavior in young infants is an ability that is seen more readily as a familiarity preference at first and as a novelty preference later. This assumes that stimuli differing in configuration tend to produce novelty preferences once they are appropriately processed, or once sensitization effects are overcome or are no longer operating. Cohen (1976) suggested that showing a novelty preference may be related not only to processing capabilities and influences on them but also to the ability to inhibit looking at the familiar stimulus (attention releasing) and thus be able to shift to the novel stimulus. If so, such stimulus inhibition (i.e., pattern novelty) behavior may be related to spatial "inhibition of return" (i.e., location novelty; see Clohessy, Posner, Rothbart, & Vecera, 1991; Johnson, 1990; Ruff & Rothbart, 1996). Data are sparse with respect to what types of inhibitory control systems, if any, may be present during the neonatal period. To our knowledge, the only study of such behavior during this period (prior to about 2 months of age) has been in the context of studying eye movements for visual orienting to understand the development of the engagement–disengagement–shifting visual attention processes. Atkinson, Hood, Wattam-Bell, and Braddick (1992) proposed that the inability to disengage may reflect the operation of a subcortical orienting system subserved by the superior colliculus without inhibitory control from the cortex, which normally functions at about 3 months but continues to develop for a number of years. Moreover, because Rothbart and colleagues (see Rothbart, Posner, & Rosicky, 1994) have not found spatial inhibition (i.e., location novelty) prior to about 3 months or stimulus inhibition (i.e., pattern novelty) prior to about 6 months with their method, it would seem speculative to propose that neonates have such capabilities. It also would be counter to the brain mechanisms and development proposed to mediate such behavior (see Braddick & Atkinson, 1988; Johnson, 1990; Posner, 1988). Rather, because measures of recognition memory more typically are interpreted as resulting from the degree of accuracy or completeness of the encoded engram from the presented information (Rose et al., 1988), it seems plausible that the familiarity preferences recorded at the younger ages in the more demanding condition essentially are the result of incomplete processing due to more competing influences when more aroused, here prior to feeding. Indeed, infants at the youngest ages did show novelty preferences when they were less aroused.

By extension, it is possible that very young infants may exhibit novelty preferences even under internally more arousing conditions if they are provided with more readily encoded stimuli or with longer processing time, a proposition not as yet systematically tested. Furthermore, with regard to the 4-month-olds, it is possible that a preference shift may be evoked toward familiarity if the older infants are given more complex stimuli or fewer encoding possibilities. Examination of the stimulus for a familiarization criterion of less than 10 s, or shortening of the test trial period

---

[2] One possible mechanism by which feeding could have an effect is by producing low-intensity synchronous firing of the reticular formation from action of the intestines via afferent projections of the vagus nerve through the solitary tract of the medulla (Beckstead & Norgren, 1979; Magnes, Moruzzi, & Pompeiano, 1961; Morest, 1967; Sessle, 1973). Such low-intensity synchronous firing after feeding, in contrast to higher intensity, more asynchronous firing prior to feeding, could reduce or make more organized the amount of endogenous stimulation to a variety of areas involved in sensorimotor orienting processes, such as the reticular–mesencephalic projections of the specific and nonspecific tracts of the sensory systems as well as the lateral geniculate, superior colliculus, pretectum, and limbic system, which in turn could result in an integrated behavioral pattern of response to feeding.

below that presently used, theoretically could be interesting but was beyond the scope of the present study. In this respect, Richards (1997) investigated single looks and different phases of attention as defined by heart rate changes with these shorter time epochs and found that in both 3- and 6-month-olds, 2.5- and 5-s brief exposures produced familiarity preferences, whereas 10- and 20-s exposures produced novelty preferences for specific visual stimuli. However, he also concluded that there was a linear relationship between exposure during sustained attention and subsequent novelty preferences. Whether such an explanation can account for younger infants' arousal-modulated recognition memory remains to be demonstrated, especially with respect to heart rate change patterns of neonates as opposed to older infants.

It also is possible that even 4-month-olds still could have shown the effect of arousal on novelty preferences under other conditions because visual recognition memory could be cognitively more taxing than differential looking on a visual preference task. For instance, manipulation of arousal to produce a greater disparity than that produced between before and after feeding might bring about differences in novelty preferences even at 4 months of age. However, because we are dealing with alert, attending infants in the awake state, it is difficult to find other means of modulating internal arousal and still have infants who are not asleep or fussing too much to attend. Because the time it took to reach the familiarization criterion did not differ across arousal conditions within an age and significant preferences were obtained in all conditions at all ages, we assumed that any differences in novelty preferences between conditions were due to feeding and not to infants' being too fidgety or irritable to attend to and process the stimuli. Although we could only speculate as to the mechanisms involved in how feeding-based arousal modulation might affect visual recognition memory and how this might interact with the complexity of the stimulus and the time allowed for familiarization, we certainly could assume that when differences were found, they were due to effects on processing stimulus information when infants were more aroused.

The design and findings from the present study raise a number of other theoretical and methodological issues. The data indicate that even very young infants recognize visual patterns and show familiarity–novelty preferences different from chance levels in circumstances of a single trial presentation. The longitudinal data support our belief that a one-trial paired-comparison recognition memory procedure is appropriate for all three age groups used in this study, even with infants tested as early as the first few days of life. The lack of infant attrition in this short procedure also is noteworthy and adds to its utility. Typical experimenter- or infant-controlled habituation tasks with high percentage novelty scores that also report high attrition rates may reflect a sample bias away from including those infants whose novelty scores may be closer to chance levels. However, low but significant novelty scores are not uncommon in 4-month-olds. Novelty scores similar to those obtained here (at the 53%–55% level) have been found in some studies with similar cohorts using different visual recognition memory techniques (e.g., Colombo et al., 1988; Fagan, 1984; Fantz & Miranda, 1977). We would predict higher scores with perhaps somewhat different or more stringent procedural factors such as infants sitting alone or on experimenters' rather than caregivers' laps. Also, the amount of time we selected for accumulation for familiarization criteria may have been less than optimal for obtaining the highest novelty scores at 4 months (see Footnote 1).

In the present study, the 4-month-old infants appeared to be sensitive to the particular visual stimulus viewed, whereas the younger infants did not. We initially hypothesized that younger infants should be more sensitive because of possible differences in stimulus energy (e.g., amount of contour) and that older infants should be more sensitive to the experiential effects of prior exposure. We found, however, that the 4-month-olds had stronger novelty preferences to the sunburst pattern, which appears to be consistent with the dual-process model (Kaplan et al., 1991) in that this stimulus with greater stimulus energy was more facilitative. That these older infants showed this effect only postfeeding is interesting. It is possible that in our design the older infants still showed some subtle remnant of an arousal condition effect in their reaction to exogenous stimulation. At younger ages, however, the lack of a stimulus effect may have been due to behavior being more dominated by internal arousal effects than by external stimulus effects. It also is possible that younger infants may not be as sensitive to pattern configuration differences as older infants (e.g., Maisel & Karmel, 1978), and thus they may have treated the two stimuli more equivalently, although the younger infants obviously could discriminate the stimuli as attested by their familiarity–novelty preferences. Because we obtained significant preferences in all conditions at all ages and because there were no differences in the amount of time needed to reach criterion in different conditions, this pattern saliency effect is an interesting finding but a side issue to the general conclusions drawn from the study regarding visual recognition memory and arousal modulation. Nevertheless, the tendency toward being affected by stimulus-specific parameters and experience rather than by parameters pertaining to endogenous arousal supports the hypothesis that the infants' performance after 2 to 3 months of age was less bound by the autoregulatory homeostatic characteristics of earlier phases of development.

The present findings are consistent with the view (Richards, 1997; Rose et al., 1982; Slater et al., 1982, 1983) that developmental age, type of stimulus, and length of exposure, to which we would add arousal level, all contribute to produce either familiarity or novelty preferences. However, especially in very young infants, it may not be sufficient to control state by having a quiet, alert infant. Slater (1995) indicated that the optimal time for testing is immediately after feeding, with infants tested midfeeding either falling asleep or giving unreliable responses. For different reasons, we (see Gardner & Karmel, 1983) would propose that the unreliability found midfeeding likely was an arousal effect, either with infants showing responses midway between less and more aroused or some infants behaving as if satiated and others as if hungry. An arousal-based mechanism could account for the fact that immediately before feeding infants show differential responding in opposite ways, whereas an unreliablility-based mechanism would assume a breakdown in processing and suggest even greater unreliability just prior to feeding rather than a shift to opposite behavior. Finally, we also point out that just because the infants seem to be attentive and looking at the stimulus does not mean that optimal processing of information is occurring. Regardless of the mechanism involved, our data suggest that controlling the situation by having a constant feeding state, similar to controlling the stimulus and the length of exposure, is necessary when studying young infants. Richards (1997) proposed that measuring heart responses during attention is important for understanding what infants are processing. We would amend this to include experimenter control of arousal effects, as interactions of information processing with internal arousal may occur that might not be easily understood even in heart rate or heart rate variability measures, and relying on a particular percent novelty preference to specify infants' performance in the absence of these controls may be misleading.

References

Anokhin, P. K., & Shuleikina, K. V. (1977). System organization of alimentary behavior in the newborn and the developing cat. *Developmental Psychobiology, 19,* 385–419.

Atkinson, J., & Hood, B. (1997). Development of visual attention. In J. A. Burack & J. T. Enns (Eds.), *Attention, development, and psychopathology* (pp. 31–54). London: Guilford Press.

Atkinson, J., Hood, B., Wattam-Bell, J., & Braddick, O. J. (1992). Changes in infants' ability to switch attention in the first three months. *Perception, 21,* 643–653.

Ballard, J. L., Novak, K. K., & Driver, M. (1979). A simplified score for assessment of fetal maturation of newly born infants. *Journal of Pediatrics, 95,* 769–774.

Bayley, N. (1969). *Bayley Scales of Infant Development.* New York: Psychological Corporation.

Bayley, N. (1993). *Bayley Scales of Infant Development* (2nd ed.). San Antonio, TX: Psychological Corporation.

Beckstead, R. M., & Norgren, R. (1979). Autoradiographic examination of the central distribution of the trigeminal, facial, glossopharyngeal, and vagal nerves in the monkey. *Journal of Comparative Neurology, 184,* 455–472.

Benasich, A. A., & Bejar, I. I. (1992). The Fagan test of infant intelligence: A critical review. *Journal of Applied Developmental Psychology, 13,* 153–171.

Bower, T. G. R. (1989). *The rational infant.* New York: Freeman.

Braddick, O., & Atkinson, J. (1988). Sensory selectivity, attentional control, and cross-channel integration in early visual development. In A. Yonas (Ed.), *Minnesota Symposia on Child Development: Vol. 20. Perceptual development in infancy* (pp. 105–143). Hillsdale, NJ: Erlbaum.

Bronson, G. W. (1974). The postnatal growth of visual capacity. *Child Development, 45,* 265–276.

Bronson, G. W. (1982). Structure, status and characteristics of the nervous system at birth. In P. Stratton (Ed.), *The psychobiology of the human newborn* (pp. 99–118). Chichester, England: Wiley.

Caron, A. J., Caron, R. F., Minichiello, M. D., Weiss, S. J., & Friedman, S. L. (1977). Constraints on the use of the familiarization-novelty method in the assessment of infant discrimination. *Child Development, 48,* 747–762.

Casaer, P., & Eggermont, E. (1985). Neonatal clinical neurological assessment. In S. Harel & N. J. Anastasiow (Eds.), *The at-risk infant: Psycho/socio/medical aspects* (pp. 197–220). Baltimore: Brooks.

Chisholm, J. S. (1978). Swaddling, cradleboards and the development of children. *Early Human Development, 2,* 255–275.

Clohessy, A. B., Posner, M. I., Rothbart, M. K., & Vecera, S. P. (1991). The development of inhibition of return in early infancy. *Journal of Cognitive Neuroscience, 3,* 345–350.

Cohen, L. B. (1976). Habituation of infant visual attention. In T. Tighe & R. N. Leaton (Eds.), *Habituation: Perspectives from child development, animal behavior and neurophysiology* (pp. 207–238). Hillsdale, NJ: Erlbaum.

Cohen, L. B., & Gelber, E. R. (1975). Infant visual memory. In L. B. Cohen & P. Salapatek (Eds.), *Infant perception: From sensation to cognition* (Vol. 1, pp. 347–403). New York: Academic Press.

Colombo, J., Mitchell, D. W., & Horowitz, F. D. (1988). Infant visual attention in the paired-comparison paradigm: Test–retest and attention performance relations. *Child Development, 59,* 1198–1210.

Colombo, J., O'Brien, M., Mitchell, D. W., & Horowitz, F. D. (1986). Stimulus salience and relational task performance. *Infant Behavior and Development, 9,* 377–380.

Ellingson, R. J. (1967). The study of brain electrical activity in infants. In L. P. Lipsitt & C. C. Spiker (Eds.), *Advances in child development and behavior* (Vol. 3, pp. 53–97). New York: Academic Press.

Fagan, J. F. (1984). The relationship of novelty preferences during infancy to later intelligence and later recognition memory. *Intelligence, 8,* 339–346.

Fagan, J. F., & Singer, L. T. (1983). Infant recognition memory as a measure of intelligence. In C. Rovee-Collier & L. P. Lipsitt (Eds.), *Advances in infancy research* (Vol. 2, pp. 31–77). Norwood, NJ: Ablex.

Fantz, R. L. (1964). The origin of form perception. *Scientific American, 204,* 66–72.

Fantz, R. L., & Miranda, S. B. (1977). Visual processing in the newborn, preterm, and mentally high-risk infant. In L. Gluck (Ed.), *Intrauterine asphyxia and the developing fetal brain* (pp. 453–471). Chicago: Year Book Medical.

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

Gardner, J. M., & Dowd, J. (1983). *Neonatal heart rate as a function of stimulus frequency.* Unpublished manuscript.

Gardner, J. M., & Karmel, B. Z. (1983). Attention and arousal in preterm and full-term neonates. In T. Field & A. Sostek (Eds.), *Infants born at risk: Physiological, perceptual and cognitive processes* (pp. 69–98). New York: Grune & Stratton.

Gardner, J. M., & Karmel, B. Z. (1984). Arousal effects on visual preferences in neonates. *Developmental Psychology, 20,* 374–377.

Gardner, J. M., & Karmel, B. Z. (1995). Development of arousal-modulated visual preferences in early infancy. *Developmental Psychology, 31,* 473–482.

Gardner, J. M., Karmel, B. Z., & Magnano, C. L. (1992). Arousal/visual preference interactions in high-risk neonates. *Developmental Psychology, 28,* 821–830.

Gardner, J. M., Karmel, B. Z., Magnano, C. L., Norton, K. I., & Brown, E. G. (1990). Neurobehavioral indicators of early brain insult. *Developmental Psychology, 26,* 563–575.

Gardner, J. M., Lewkowicz, D. J., Rose, S. A., & Karmel, B. Z. (1986). Effects of visual and auditory stimulation on subsequent visual preferences in neonates. *International Journal of Behavioral Development, 9,* 251–263.

Gardner, J. M., & Turkewitz, G. (1982). The effect of arousal level on visual preferences in preterm infants. *Infant Behavior and Development, 5,* 369–385.

Gerrity, K. M., & Woodruff, D. S. (1979, March). *Central nervous system maturation and infant visual development.* Paper presented at the biennial meeting of the Society for Research in Child Development, Detroit, MI.

Giacoman, S. L. (1971). Hunger and motor restraint on arousal in visual attention in the infant. *Child Development, 42,* 605–614.

Hoffmann, R. (1978). Developmental changes in human infant visual-evoked potentials to patterned stimuli recorded at different scalp locations. *Child Development, 49,* 110–118.

Hunter, M. A., Ames, E. W., & Koopman, R. (1983). Effects of stimulus complexity and familiarization time on infant preferences for novel and familiar stimuli. *Developmental Psychology, 19,* 338–352.

Johnson, M. H. (1990). Cortical maturation and the development of visual attention in early infancy. *Journal of Cognitive Neuroscience, 2,* 81–95.

Johnson, M. H. (1996). From cortex to cognition: Cognitive neuroscience studies of infant attention and perception. In C. Rovee-Collier & L. P. Lipsitt (Eds.), *Advances in infancy research* (Vol. 10, pp. 161–217). Norwood, NJ: Ablex.

Johnson, M. H., & Morton, J. (1991). *Biology and cognitive development: The case of face recognition.* Oxford, England: Basil Blackwell.

Kaplan, P., Fox, K., Scheuneman, D., & Jenkins, L. (1991). Cross-modal facilitation of infant visual fixation: Temporal and intensity effects. *Infant Behavior and Development, 14,* 83–109.

Kaplan, P., & Werner, J. S. (1991). Implications of a sensitization process for the analysis of visual attention. In M. J. S. Weiss & P. R. Zelazo (Eds.), *Newborn attention: Biological constraints and the influence of experience* (pp. 278–307). Norwood, NJ: Ablex.

Karmel, B. Z. (1969). Complexity, amount of contour, and visually dependent preference behavior in hooded rats, domestic chicks, and human infants. *Journal of Comparative and Physiological Psychology, 69,* 326–336.

Karmel, B. Z., & Gardner, J. M. (1996). Prenatal cocaine exposure effects on arousal-modulated attention during the neonatal period. *Developmental Psychobiology, 29,* 463–480.

Karmel, B. Z., Gardner, J. M., & Freedland, R. L. (1996). Arousal-modulated attention at four months as a function of intrauterine cocaine exposure and central nervous system injury. *Journal of Pediatric Psychology, 21,* 821–832.

Karmel, B. Z., Gardner, J. M., & Magnano, C. L. (1991). Attention and arousal in early infancy. In M. J. S. Weiss & P. R. Zelazo (Eds.), *Newborn attention: Biological constraints and the influence of experience* (pp. 339–376). Norwood, NJ: Ablex.

Karmel, B. Z., Gardner, J. M., Zappulla, R. A., Magnano, C. L., & Brown, E. G. (1988). Brainstem auditory evoked responses as indicators of early brain insult. *Journal of Electroencephalography and Clinical Neurophysiology, 71,* 429–442.

Karmel, B. Z., & Maisel, E. B. (1975). A neuronal activity model for infant visual attention. In L. B. Cohen & P. Salapatek (Eds.), *Infant perception: From sensation to cognition* (Vol. 1, pp. 77–131). New York: Academic Press.

Kleiner, K. A. (1993). Specific vs. non-specific face recognition device. In B. de Boysson-Bardies, S. de Schonen, P. Jusczyk, P. MacNeilage, & J. Morton (Eds.), *Developmental neurocognition: Speech and face processing in the first year of life* (pp. 103–108). Dordrecht, the Netherlands: Kluwer Academic.

Kleiner, K. A., & Banks, M. S. (1987). Stimulus energy does not account for 2-month-olds' face preferences. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 594–600.

Korner, A. F. (1972). State as variable, as obstacle, and as mediator of stimulation in infant research. *Merrill-Palmer Quarterly, 18,* 77–94.

Kukorelli, T., & Juhasz, G. (1977). Sleep induced by intestinal stimulation in cats. *Physiology and Behavior, 19,* 355–358.

Lewis, T. L., Mondloch, C. J., Budreau, D. R., Maurer, D., Dannemiller, J. L., Stephens, B. R., & Kleiner, K. A. (1998). Face perception in young infants [Abstract]. *Infant Behavior and Development, 21,* p. 535. (Special issue on the International Conference on Infant Studies)

Lewkowicz, D. J. (1985a). Bisensory response to temporal frequency in 4-month-old infants. *Developmental Psychology, 21,* 306–317.

Lewkowicz, D. J. (1985b). Developmental changes in infants' response to temporal frequency. *Developmental Psychology, 21,* 858–865.

Lewkowicz, D. J., & Turkewitz, G. (1981). Intersensory interaction in newborns: Modification of visual preferences following exposure to sound. *Child Development, 51,* 1295–1298.

Lindsley, D. B., & Wicke, J. D. (1974). The electroencephalogram: Autonomous electrical activity in man and animals. In R. F. Thompson & M. M. Patterson (Eds.), *Bioelectric recording techniques* (Pt. B, pp. 3–83). New York: Academic Press.

Lipton, E. L., Steinschneider, A., & Richmond, J. B. (1965). Swaddling, a child practice: Historical, cultural, and experimental observations. *Pediatrics, 35,* 521–567.

Magnes, J., Moruzzi, G., & Pompeiano, O. (1961). Synchronization of the EEG produced by low-frequency electrical stimulation of the region of the solitary tract. *Archives Italiennes de Biologie, 99,* 33–67.

Maisel, E. B., & Karmel, B. Z. (1978). Contour density and pattern configuration in visual preferences in infants. *Infant Behavior and Development, 1,* 127–140.

Maurer, D. (1985). Infants' perception of facedness. In T. M. Field & N. Fox (Eds.), *Social perception in infants* (pp. 73–100). Norwood, NJ: Ablex.

Maurer, D., & Lewis, T. L. (1979). A physiologic explanation of infants' early visual development. *Canadian Journal of Psychology, 33,* 232–252.

McCarvill, S. L., & Karmel, B. Z. (1976). A neural activity interpretation of luminance effects on infant pattern preferences. *Journal of Experimental Child Psychology, 22,* 363–374.

McGraw, M. (1943). *The neuromuscular maturation of the human infant.* New York: Hafner Press.

Milewski, A. E., & Siqueland, E. R. (1975). Discrimination of color and pattern novelty in one-month human infants. *Journal of Experimental Child Psychology, 19,* 122–136.

Morest, D. K. (1967). Experimental study of the projections of the nucleus of the tractus solitarius and the area postrema in the cat. *Journal of Comparative Neurology, 130,* 277–300.

Morton, J., & Johnson, M. H. (1991). CONSPEC and CONLERN: A two-process theory of infant face recognition. *Psychological Review, 98,* 164–181.

Mundy, P. C. (1984). The effects of stimulus preferences on infants' attention to novel stimuli. *Child Study Journal, 14,* 287–300.

Pomerleau-Malcuit, A., & Clifton, R. K. (1973). Neonatal heart rate response to tactile, auditory, and vestibular stimulation in different states. *Child Development, 44,* 485–496.

Posner, M. I. (1988). Structures and functions of selective attention. In T. Boll & T. Bryant (Eds.), *Master lectures in clinical neuropsychology and brain function: Research, measurement, and practice* (pp. 171–202). Washington, DC: American Psychological Association.

Richards, J. E. (1988). Heart rate offset responses to visual stimuli in infants from 14–26 weeks of age. *Psychophysiology, 25,* 278–286.

Richards, J. E. (1997). Effects of attention on infants' preference for briefly exposed visual stimuli in the paired-comparison recognition-memory paradigm. *Developmental Psychology, 33,* 22–31.

Rose, S. A. (1980). Enhancing visual recognition memory in preterm infants. *Developmental Psychology, 16,* 85–92.

Rose, S. A. (1988). Shape recognition in infancy: Visual integration of sequential information. *Child Development, 59,* 1161–1176.

Rose, S. A., Feldman, J. F., Wallace, I. F., & McCarton, C. M. (1988). Individual differences in infants' information processing: Reliability, stability, and prediction. *Child Development, 59,* 1177–1197.

Rose, S. A., Gottfried, A. W., Melloy-Carminar, P., & Bridger, W. H. (1982). Familiarity and novelty preferences in infant recognition memory: Implications for information processing. *Developmental Psychology, 18,* 704–713.

Rothbart, M. K., Posner, M. I., & Rosicky, J. (1994). Orienting in normal and pathological development. *Developmental Psychopathology, 6,* 635–652.

Rothbart, M. K., Ziaie, H., & O'Boyle, C. G. (1992). Self-regulation and emotion in infancy. *New Directions for Child Development, 55,* 7–24.

Ruff, H. A., & Rothbart, M. K. (1996). *Attention in early development: Themes and variations.* New York: Oxford University Press.

Ruff, H. A., & Turkewitz, G. (1975). Developmental changes in the effectiveness of stimulus intensity on infant visual attention. *Developmental Psychology, 11,* 705–710.

Ruff, H. A., & Turkewitz, G. (1979). Changing role of stimulus intensity as a determinant of infants' attention. *Perceptual and Motor Skills, 48,* 815–826.

Saayman, G., Ames, E. W., & Moffett, A. (1964). Response to novelty as an indicator of visual discrimination in the human infant. *Journal of Experimental Child Psychology, 1,* 189–198.

Salapatek, P. (1975). Pattern perception in early infancy. In L. B. Cohen & P. Salapatek (Eds.), *Infant perception: From sensation to cognition* (Vol. 1, pp. 133–248). New York: Academic Press.

Sessle, B. J. (1973). Excitatory and inhibitory inputs to single neurons in the solitary tract nucleus and adjacent reticular formation. *Brain Research, 53,* 319–331.

Slater, A. (1995). Visual perception and memory at birth. In C. Rovee-Collier & L. P. Lipsitt (Eds.), *Advances in infancy research* (Vol. 9, pp. 107–162). Norwood, NJ: Ablex.

Slater, A., & Morison, V. (1991). Visual attention and memory at birth. In M. J. S. Weiss & P. R. Zelazo (Eds.), *Newborn attention: Biological constraints and the influence of experience* (pp. 256–277). Norwood, NJ: Ablex.

Slater, A., Morison, V., & Rose, D. (1982). Visual memory at birth. *British Journal of Psychology, 73,* 519–525.

Slater, A., Morison, V., & Rose, D. (1983). Perception of shape by the newborn baby. *British Journal of Developmental Psychology, 1,* 135–142.

Turkewitz, G., Gardner, J. M., & Lewkowicz, D. J. (1984). Sensory/perceptual functioning during early infancy: The implications of a quantitative basis for responding. In G. Greenberg & E. Tobach (Eds.), *Behavioral evolution and integrative levels* (pp. 167–195). Hillsdale, NJ: Erlbaum.

Turkewitz, G., Lewkowicz, D. J., & Gardner, J. M. (1983). Determinants of infant perception. In J. Rosenblatt, R. A. Hinde, C. Beer, & M. Busnel (Eds.), *Advances in the study of behavior* (Vol. 13, pp. 39–62). New York: Academic Press.

Werner, J. S., & Siqueland, E. R. (1978). Visual recognition memory in the preterm infant. *Infant Behavior and Development, 1,* 79–94.

Woodruff, D. S. (1978). Brain electrical activity and behavior relationships over the life span. In P. Baltes (Ed.), *Life span development* (Vol. 1, pp. 111–179). New York: Academic Press.

Woroby, J. (1986). Neonatal stability and one-month behavior. *Infant Behavior and Development, 9,* 119–124.

Zeskind, P. S., & Marshall, T. R. (1991). Temporal organization in neonatal arousal: Systems, oscillations, and development. In M. J. S. Weiss & P. R. Zelazo (Eds.), *Newborn attention: Biological constraints and the influence of experience* (pp. 22–62). Norwood, NJ: Albex.

Received August 25, 1997
Revision received August 7, 1998
Accepted August 10, 1998 ■