Arousal-Modulated Attention At Four Months as a Function of Intrauterine Cocaine Exposure and Central Nervous System Injury

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CNS-compromised neonates are poor modulators tending to prefer less stimulation in all arousal conditions. Cocaine-exposed neonates also are poor modulators but tend to prefer more stimulation in all arousal conditions. Infants (N = 359, M = 4 months) were divided into 6 CNS injury groups and 1 cocaine-exposed, non-CNS-injured group and tested in three arousal conditions: less aroused (after feeding), more aroused-endogenous (before feeding), and more aroused-exogenous (after feeding with additional stimulation prior to each trial). Infants with CNS injuries still showed some degree of influence of arousal on attention that was now similar to that seen in normal neonates and 1-month-olds, while cocaine-exposed infants, 4-month-old normal and mild or moderate CNS-injury infants did not.

KEY WORDS: arousal-modulated attention; infants; intrauterine cocaine exposure; early CNS injury; visual preferences; dopamine; visual attention.

Arousal, attention, and state-regulating capacities are fundamental neurobehavioral processes mediated by an adequately functioning CNS and form the basis for subsequent development (Field, 1981; Gardner, Karmel, & Magnano, 1994). This research was supported in part by National Institute of Drug Abuse grants R01-DA-06644 awarded to Bernard Z. Karmel and K21-DA-00236 awarded to Robert L. Freedland, and a National Institute of Child Health and Human Development Grant R01-HD-21784 awarded to Judith M. Gardner. We thank Elise Conway, Amy Del Rosario, Lazinka Smith, and Sean Rotkowitz for their assistance in data gathering and recruitment, and Lawrence Black for help in manuscript preparation. Portions of these data were presented at the meetings of the Society for Research in Child Development, Indianapolis, 1994, and the International Society for the Study of Behavioral Development, 1994.

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Early development of these capacities in normal infants appears to follow CNS maturation and development as opposed to specific learned experience (Fantz, Fagan, & Miranda, 1975; Gardner & Karmel, 1995).

Initially during the neonatal period, normal neonates modulate their attention as a function of arousal. That is, 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 (see Karmel, Gardner, & Magnano, 1991; Turkewitz, Gardner, & Lewkowicz, 1984; Zeskind & Marshall, 1991). When more aroused, neonates prefer less stimulation and when less aroused, they prefer more stimulation. This arousal-modulated attention (AMAtt) effect has been verified in a series of studies that demonstrated systematic shifts in visual preferences toward slower temporal frequencies (slower rates of change) or larger spatial frequencies (less contour) in stationary patterns when neonates were (a) endogenously more aroused (before feeding) as opposed to less aroused (after feeding) (Gardner et al., 1992); and (b) exogenously more aroused due to increased amounts of pre- or concurrent stimulation within or between modalities (Gardner & Karmel, 1995; Gardner, Lewkowicz, Rose, & Karmel, 1986).

Neonates who sustained CNS compromise (Gardner et al., 1992) or who were cocaine-exposed in utero (Karmel & Gardner, 1996) show deficits in the AMAtt effect in that they tend not to shift preferences as a function of arousal as much as infants without such etiologies. Although both etiologies produce reductions in the magnitude of the AMAtt effect, the reductions are in the opposite direction. CNS-injured infants tend to prefer slower frequencies and do not shift toward higher frequencies when less aroused, whereas cocaine-exposed infants tend to prefer higher frequencies and do not shift toward lower frequencies when more aroused. This pattern remains constant throughout the neonatal period (newborn to 1-2 months corrected age). Thus, during the neonatal period, both reduced magnitudes and differential directions of shift in AMAtt effects have been shown as a function of CNS injury or intrauterine cocaine exposure.

After the neonatal period, usually by 2-3 months of age, manipulations of simple stimulus energy and energy changes are less significant contributors to looking preferences in normal infants. Rather, specific changes in higher order features of the visual stimulus are more important determinants of behavior (Karmel & Maisel, 1975). For example, in infants younger than but not after 2 months, contour density preferences can be altered by changing the brightness of the stimulus (McCarvill & Karmel, 1976), and pattern preferences can be altered by changing the total pattern size (Maisel & Karmel, 1978; Ruff & Turkewitz, 1975), or pattern brightness (Ruff & Turkewitz, 1979). After 2 months, shifts based on facial recognition also appear to occur (Maurer, 1985; Morton & Johnson, 1991). This developmental shift to higher order sensory-specific determinants of behavior is speculated by some to relate to emergent cortical development and its subsequent influence on subcortical mechanisms (Karmel et al.,
1991; Morton & Johnson, 1991). However, others (Colombo, 1995) have argued for differential development of systems that transcend both cortical and subcortical regions involving the geniculostriate system in interaction with anterior and posterior attentional systems.

On a behavioral level, this early 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 more to be influenced by stimulus structure (Kleiner & Banks, 1987); others maintain that stimulus energy or intensity remains a factor in attention even at 4 months, depending on the situation along with physical characteristics of the stimulus (Kaplan, Fox, Scheuneman, & Jenkins, 1991; Lewkowicz, 1985); and still others espouse the view that newborns function on the same basis as older infants but the problem is in devising experimental ways of tapping into their capabilities (Bower, 1989).

Our studies indicate that healthy 4-month-olds show no differences among arousal conditions and look significantly more at faster than at slower frequencies in all conditions used to test the AMAtt effect (Gardner & Karmel, 1995). Thus, by 4 months of age, the methods of arousal modulation that were effective in controlling attention in the neonate (i.e., feeding, prestimulation) no longer hold. This results presumably after the spurt in brain growth reflecting maturation of specific sensory systems in the primary and secondary regions of the cerebral cortex (Karmel et al., 1991). Properties of the external stimulus alone (Gardner & Karmel, 1995), repeated experience or novelty (Rose & Wallace, 1985), or short-term memory (Rovee-Collier, Schechter, Shyi, & Shields, 1992) are now factors in dominating and controlling attention. It has not yet been fully explored how these factors are affected by conditions that may alter CNS integrity over these early periods of CNS development.

Under the controlled testing procedures in our studies, CNS-compromised neonates are poor modulators tending to prefer less stimulation in all arousal conditions. Cocaine-exposed neonates also are poor modulators but tend to prefer more stimulation in all arousal conditions. On the other hand, normal infants, who modulate attention as neonates and prefer more stimulation when less aroused and less stimulation when more aroused, by 4 months, prefer more stimulation in all arousal conditions. In this paper we investigated whether the changes in AMAtt by 4 months were still affected by neonatal CNS injury or intrauterine cocaine exposure.

**METHOD**

**Participants**

Infants (N = 359) recruited from the NICU and term nursery as neonates were tested at 4 months postconceptional age. Most (93%) infants had been
tested as neonates on similar procedures previously reported by us (Gardner &
Karmel, 1995; Karmel & Gardner, 1996). Infants were excluded who had chro-
mosomal or congenital abnormalities, or whose mothers were known positive for
HIV. Of the population recruited, 51% were 37 or more weeks gestation at birth
based on examination (Ballard, Novak, & Driver, 1979). Of these infants, 44%
were assigned to the NICU as were all infants <36 weeks. The ethnicity of the
infants was 43% Caucasian, 40% black, 13% Hispanic, and 4% other. All infants
were tested at postterm ages corrected for degree of prematurity. Mean corrected
age at test was 4.25 months (SD = 0.32).

CNS status was confirmed during the newborn period for the NICU infants
by cranial ultrasonographic and brainstem auditory evoked response (BAER)
tests conducted according to similar clinical protocols. Both tests were per-
formed during the first week of life with the exception that initial BAER testing
did not occur until 32 weeks gestation if infants were born <32 weeks. If initially
abnormal or suspect, tests were repeated at biweekly intervals until resolution
occurred. Term nursery infants received BAERs as part of a research (not clini-
cal) protocol. Since term nursery infants were considered healthy enough not to
warrant routine ultrasound testing for clinical reasons, CNS status was based on
BAER findings alone. It should be noted that even when ultrasounds were not
performed, the likelihood of finding any structural brain abnormality on ultrasonic
in infants with normal brainstem auditory evoked responses is no more than 5–6%.
This is true even in a high-risk population tested as early as 30 weeks gestational age (Karmel, Gardner, Zappulla, Magnano, & Brown, 1988). More
detailed criteria for CNS injury were provided in Gardner, Karmel, Magnano,
Norton, and Brown (1990) and are detailed in Table I (Groups 1–6).

Table I. Criteria for Brain Insult Groups Used in Subsequent Analyses

<table>
<thead>
<tr>
<th>Group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. NICU-normal</td>
<td>Normal ultrasound, normal brainstem auditory evoked response (BAER).</td>
</tr>
<tr>
<td>2. BAER-only</td>
<td>Normal ultrasound, abnormal BAER.</td>
</tr>
<tr>
<td>3. Mild</td>
<td>Subependymal (SE) or intraventricular (IV) hemorrhage alone or with tiny SE cysts; lobular or prominent choroids (questionable IV extension); tiny SE or choroid cysts; questionable or uncertain ultrasound</td>
</tr>
<tr>
<td>4. Moderate</td>
<td>IV hemorrhage with SE or choroid cysts; ventriculomegaly &lt;5mm, cerebral edema alone</td>
</tr>
<tr>
<td>5. Strong</td>
<td>IV hemorrhage; ventriculomegaly 5-10 mm; periventricular or parenchymal leukomalacia (LM), hyperechoic echogenicity, or multiple cysts &gt;3 mm; subarachnoid hemorrhage; cerebral edema &gt;48 hrs with IV hemorrhage or LM</td>
</tr>
<tr>
<td>6. Severe</td>
<td>IV hemorrhage; ventriculomegaly &gt;10 mm; hemorrhage or dilatation of IIIrd or IVth ventricle; large or multiple sites of porencephaly; parenchymal hemorrhage, or other parenchymal infarct; seizures requiring treatment</td>
</tr>
</tbody>
</table>
Table II. Demographic Data of Subjects in Study*

<table>
<thead>
<tr>
<th>CNS injury group*</th>
<th>n</th>
<th>BW (grams)</th>
<th>EGA (weeks)</th>
<th>HC (cm)</th>
<th>Length (cm)</th>
<th>1 min</th>
<th>5 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Normal</td>
<td>147</td>
<td>2871.2</td>
<td>37.7</td>
<td>32.4</td>
<td>47.0</td>
<td>7.8</td>
<td>8.6</td>
</tr>
<tr>
<td>2. BAER-only</td>
<td>53</td>
<td>1991.4</td>
<td>34.1</td>
<td>30.2</td>
<td>43.0</td>
<td>7.1</td>
<td>8.3</td>
</tr>
<tr>
<td>3. Mild</td>
<td>39</td>
<td>1881.4</td>
<td>32.6</td>
<td>29.4</td>
<td>42.7</td>
<td>6.5</td>
<td>7.9</td>
</tr>
<tr>
<td>4. Moderate</td>
<td>34</td>
<td>1379.6</td>
<td>30.3</td>
<td>27.9</td>
<td>38.6</td>
<td>6.0</td>
<td>7.4</td>
</tr>
<tr>
<td>5. Strong</td>
<td>18</td>
<td>1261.7</td>
<td>28.8</td>
<td>25.8</td>
<td>37.1</td>
<td>5.5</td>
<td>7.4</td>
</tr>
<tr>
<td>6. Severe</td>
<td>22</td>
<td>2356.7</td>
<td>34.7</td>
<td>31.1</td>
<td>43.2</td>
<td>4.5</td>
<td>6.2</td>
</tr>
<tr>
<td>Cocaine-exposed, no CNS injury</td>
<td>46</td>
<td>2944.0</td>
<td>39.0</td>
<td>33.1</td>
<td>48.4</td>
<td>8.0</td>
<td>8.8</td>
</tr>
</tbody>
</table>

*N = 359. BW = birth weight; EGA = estimated gestational age; HC = head circumference; BAER = brainstem auditory evoked response.

Prenatal cocaine exposure was determined by maternal report, maternal or infant urine toxicology, and/or meconium toxicology. More detailed criteria for cocaine exposure were provided in Karmel and Gardner (1996). Infants were classified as positive prenatal exposure (n = 46) if (a) use was reported by the mother even if urine or meconium toxicological results (Ostrea, Brady, Parks, Asenio, & Naluz, 1989) were negative or unable to be obtained, or (b) either maternal or infant urine or infant meconium results were positive even if mothers reported that they did not use during pregnancy. No women in our sample began using during pregnancy, but rather used prior to and through all or most of their pregnancy. Infants were excluded who had negative toxicologies and whose mothers had reported using cocaine in their first trimester only. No distinction was made between level or dose or different forms of cocaine administration since many users both smoked and snorted cocaine. Because of the manner in which we recruited and based on the high cocaine metabolite levels typically obtained from the meconium assays, the cocaine-using mother in our sample was predominantly a heavier user not involved in treatment or, if in treatment, not able to control use well. Unequal distributions of infants and insufficient sample sizes across all CNS categories of cocaine-exposed infants precluded testing for the interaction of CNS injury with cocaine exposure. Therefore, only CNS normal, cocaine-exposed infants were included here with the consequence that only the simple effects of cocaine exposure or of CNS injury, but not their interaction, were able to be tested. Demographic information for the cocaine-exposed group is provided in Table II.
Stimuli and Apparatus. The apparatus, stimuli, and testing procedures were similar to those we used previously (Gardner & Karmel, 1995). The visual preference apparatus consisted of a three-sided chamber with a back panel having two openings for stimulus presentation (15.2 cm² each with inner edges 30.4 cm apart), and a centrally located peephole. Infants' eyes were approximately 50 cm from the center of each stimulus. Stimulus presentation consisted of two identically patterned light panels with a 1.28 cm² element random black and white checkerboard pattern (the ½-inch pattern from Karmel, 1969) that turned on and off at three preselected square-wave modulated frequencies between 1 and 8 Hz. Most infants (65.6%) received a 1,3,8 Hz stimulus set, 13.7% received 1,2,4 Hz, and 20.7% received 2,4,8 Hz. As reported earlier, since no differences in the slope of the visual preference function were detected among stimulus sets (Gardner & Karmel, 1995), the stimuli were collapsed across stimulus sets into a relative stimulus frequency factor (low, medium, and high). We assumed that different temporal frequencies provided higher levels of stimulation the faster the temporal frequency.

Arousal Conditions. Three tests of visual preferences were performed, one for each of the three different manipulations of arousal that we have routinely used to maximize the AMAtt effect in neonates. In the less aroused condition, infants were tested immediately after being fed. In the more aroused-endogenous condition, infants were tested within 30 minutes prior to their scheduled feeding. In the more aroused-exogenous condition, infants were tested after feeding (as when less aroused) but were exposed to additional external stimulation presented immediately before each preference trial. This pretrial stimulation consisted of an 8-Hz visual stimulus presented for 10-second periods just prior to each trial of the test. The two more aroused conditions reflect independent forms of increased arousal. That is, the more aroused-endogenous condition keeps the exogenous stimulation constant and contrasts effects of an increase in endogenously produced stimulation associated with hunger; the more aroused-exogenous condition keeps endogenously produced stimulation constant and contrasts effects of an increase in exogenous stimulation associated with prestimulation.

Testing Procedure. Infants were tested in all three arousal conditions, with each infant receiving a different random order of all six of the possible pairs of the three stimulus rates in the assigned stimulus set in each of the arousal conditions for fixed trial lengths of 15 seconds per trial. A modified Greco-Latin square paired-comparison design was used in which each of the three possible stimulus frequency pairs was presented with right–left position reversed in each half of the order with the restriction that no stimulus followed itself in the same position. Because we had demonstrated a lack of any significant effects of
condition order in previous studies in normal infants (Gardner et al., 1992), arousal condition was not counterbalanced across infants. This enabled testing around a single scheduled feed, with all infants receiving the same arousal order; that is, first tested in the more aroused-endogenous condition prior to feeding, then fed, then tested in the less aroused condition, followed by the more aroused-exogenous condition. This sequence is practical for administering all conditions around one feeding, is not overly stressful or tiring, and allowed us to test under comparable conditions in one laboratory visit.

Measures

The average time spent looking at each stimulus in the stimulus frequency set was used as the dependent variable. The AMAtt effect was tested using repeated measures, multivariate analysis of variance with two between-group factors (cocaine exposure, 2 levels; CNS injury, 6 levels) and two within-group variables (arousal level, 3 levels; stimulus frequency, 3 levels). The interaction between cocaine exposure and CNS injury was not tested, as discussed earlier, because of unequal distributions of CNS-injured infants across cocaine exposure.

RESULTS

There were no significant main effects due to cocaine exposure or CNS injury. Infants looked equally long regardless of whether cocaine exposed, $F(1, 352) = 0.98$, or CNS injured, $F(5, 352) = 0.86$. There were no significant effects associated with arousal condition, $F_m(2, 351) = 0.96$, or interaction of arousal condition with cocaine exposure, $F_m(2, 351) = 1.84$, or CNS injury, $F_m(10, 702) = 0.37$. However, an overall strong preference for the higher frequency was observed, $F_m(2, 351) = 28.01, p < .0001$, which was evidenced by a significant positive linear trend across the stimulus frequency set, $F(1, 352) = 55.56, p < .0001$.

CNS injury interacted with this stimulus trend, $F_m(2, 351) = 3.10, p < .001$, although cocaine exposure did not, $F_m(2, 351) = 0.40$. Figure 1 shows these results and plots the changes in the AMAtt effect as a function of cocaine exposure (Figure 1: CE group vs. Group 1) and CNS injury group (Figure 1: Groups 1–6). Inspection of the slopes for specific CNS injury groups revealed that the linear preference functions of infants with no detected CNS involvement (Group 1) as well as those with mild or moderate involvement (Groups 3 and 4) or cocaine exposure did not differ and were similar across arousal conditions. However, increased arousal affected looking of infants with three different types of CNS involvement in various ways. Infants with abnormal BAERs but no
detected structural involvement (Group 2) and infants with severe involvement (Group 6) appeared to shift preferences toward lower frequencies in either the more aroused-exogenous (Group 2) or both exogenous and endogenous (Group 6) conditions, while infants with strong involvement (Group 5), although generally preferring the highest frequency stimulus in all conditions, showed variability in their looking at lower frequency stimulation when in higher arousal states. We interpret such findings as indicative of a continued AMAtt effect, which was verified by separate analyses of the arousal-by-stimulus frequency interaction of the linear trends across the three arousal conditions for each CNS group. The results indicated significant arousal-by-stimulus frequency interactions for Groups 2, 5, and 6. This was due to a significant difference in the linear trends across arousal conditions for Group 2, $F(1, 52) = 8.26, p < .01$, and Group 6, $F(1, 21) = 6.17, p < .03$, as well as marginally significant differences in nonlinear (cubic and 4th order) trends across arousal for Group 6, $p's < .10$, and a significant difference in the nonlinear (4th order) trends across arousal, $F(1, 17) = 4.77, p < .05$, for Group 5. With respect to cocaine exposure alone, a similar MANOVA was performed deleting any case where CNS injury was present or suspect (Groups 2–6). This analysis revealed a significant linear trend along the stimulus frequency dimension, $F(1, 191) = 116.83, p < .0001$, with no differences detected as main effects or interactions as a function of cocaine exposure or arousal condition, all $F's < 1.14$. 

Fig. 1. The amount of time infants looked at stimulus temporal frequencies when they were in the more and less aroused conditions as a function of cocaine exposure and CNS injury (Groups 1–6). See text for detailed description of groups.
DISCUSSION

Replicating previous findings (Gardner & Karmel, 1995), normal 4-month-old infants showed no differences among arousal conditions and looked significantly more at faster than at slower frequencies in all arousal conditions. In contrast, infants with strong or severe CNS involvement or with initial abnormal BAER characteristics in the absence of any detected structural abnormalities continued to show an AMAtt effect, which is a deviation from the normal developmental pattern. Infants with the most severe CNS insults (Group 6) continued to manifest the neonatal pattern. For these severely affected infants, who as neonates tended to prefer lower frequency stimulation in all arousal conditions (Gardner et al., 1992), the AMAtt effect at 4 months now resembled the attentional pattern seen in normal neonates. They preferred faster frequencies when less aroused and slower frequencies in both endogenous and exogenous higher arousal conditions. For infants with strong CNS involvement (Group 5) or with abnormalities in neurofunction as evidenced by abnormal BAERs but no structural abnormality (Group 2), the continuation of the normal neonatal pattern seemed to be restricted to the higher endogenous arousal condition at 4 months. These continuing AMAtt effects suggest a developmental lag or deviation in adapting to exogenous and endogenous combinations of information.

Of special interest is the relatively poorer showing of BAER-only (Group 2) infants in whom attentional responses continued to be influenced by increased arousal due to endogenous stimulation. An infant in this group may have sustained brainstem injury that had a more prolonged recovery period than seen with mild to moderate CNS injury. The fact that infants with mild to moderate CNS injury (mostly in the form of intraventricular hemorrhage, i.e., Groups 3 and 4) did not show residual AMAtt effects at 4 months speaks not only to the promise of early recovery from the most common form of neonatal CNS injury, but also for the importance of an expanded examination using techniques other than cranial ultrasound to assess the types of damages and their recovery rates from early injury for a better understanding of potential outcome from early CNS insult.

On the other hand, the early influence of cocaine exposure remains an open question. In the current study, 4-month-old cocaine-exposed infants showed the same pattern of response to stimulation as when they were neonates that we characterized as stimulus-seeking regardless of arousal. Such behavior could be indicative of a precocial 4-month-like response during the neonatal period (Karmel & Gardner, 1996), which at 4 months now appears normal, but had not changed from the neonatal period. This interpretation would be consistent with the stimulus preference functions that were obtained here for both the cocaine-exposed and the nonexposed, non-CNS-injured infants. Alternatively, we could conclude that the arousal conditions employed here at 4 months and previously
for neonates, although effective in detecting differences among CNS-injured
groups, may not have been sufficient to detect differences between cocaine-
exposed and nonexposed infants. Thus, cocaine-exposed infants then might re-
quire even greater amounts or different forms of arousal or stimulation before any
modulation of attention might be observed at any age. We are currently testing
this hypothesis by using a more demanding set of arousal-modulated conditions
both for neonates and for 4-month-olds. However, to conclude that cocaine-
exposed infants, because they behave similarly at 4 months of age as nonexposed
normal infants, have recovered from the effects found during the neonatal period
may not be warranted from these data alone. If our interpretation of the interac-
tion of arousal and attention is accurate (Gardner & Karmel, 1983; Karmel &
Gardner, 1996) and appropriately functioning AMAtt systems form the bases
for later perceptual and cognitive functioning the early stimulus-seeking behav-
ior of cocaine-exposed infants could alter later development. Thus, the seeking
of more stimulation that characterizes the atypical behavior of cocaine-exposed
neonates and that shows no developmental progression through 4 months of age
could represent atypical functioning that perpetuates itself on higher levels of
behavior.

We and others have proposed that arousal and attention systems are best
understood in the context of an inherent homeostatic regulatory mechanism that
functions to maintain infants' equilibrium with their environment, and that this
equilibrium contains both a dynamic range (i.e., bandwidth) and a threshold of
activation that is self- or infant-limiting (Field, 1981; Gardner & Karmel, 1983,
1995; Karmel et al., 1991). It is possible that CNS injury and cocaine exposure
produce infants with different set points or thresholds of arousal for optimal
functioning of attention that in turn, if played out over development, could lead
to divergent developmental outcomes.

We have assumed that the AMAtt effect and its change over development
 correspond to a common biologically based developmental process. We argue
that the development of CNS systems, most likely cortical in origin, modifies the
early basic subcortical influences of arousal on attention to generate the type of
behavioral differentiation observed in the older infant. In Karmel and Maisel
(1975), we 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). We have proposed (Gardner & Karmel,
1995) that subcortical influences on attention would be reduced and specific
sensory system information would be enhanced based on the assumption that
inhibitory cortical influences in a homeostatic system would act as negative
feedback to modulate a subcortical arousal system as it projects to higher levels,
thereby producing a higher order homeostasis. In that case, the AMAtt effect
would have relatively less influence on visual preferences as compared with
sensory-specific cortical effects that now dominate. The present study represents
an initial step toward determining how this normal CNS developmental progression is altered significantly by more serious forms of CNS injury and cocaine exposure. Whether or not further alteration of attention from a normal trajectory in the affected groups continues beyond 4 months remains to be investigated.

The possibility that these behavioral effects may be mediated by alterations in mechanisms of neurotransmitter synthesis and reuptake, especially involving dopamine, is intriguing since both cocaine exposure and CNS injury produce short- and long-term alterations in those CNS systems that underlie attention and arousal behaviors (Volpe, 1995). Such effects on development are likely to be produced in different ways and result in different patterns of development; but deficits regardless of their stimulus-seeking or stimulus-avoidance effects, would lead presumably to equally adverse outcomes. Additional manipulations that could affect the AMAtt curves as they project over development then could prove useful to test out these alternative explanations of the observed shifts (or lack thereof) in attention with development as well as help elucidate the underlying CNS mechanisms involved.

Finally, from a clinical perspective, our data stress the importance of considering the individual history of the infant with respect to CNS organization and cocaine exposure in that specific forms of neuropathology and neurotoxicity differentially affect early attention. We believe that this characterization of the infant's general mode of responding to the environment, as reflected in the AMAtt effects reported here, plays an important role in subsequent development. Thus, we propose that deviant AMAtt functions underly atypical patterns over development, thereby producing divergent developmental trajectories. The duration, magnitude, and permanency of these effects are presently under study.

REFERENCES


