



## Attention and Early Brain Development

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### **Topic**

*Brain*

### **Introduction**

Attention serves several functions related to information processing. It selects certain events or objects in the environment to focus on and maintains focus on the object of interest while information provided by that object is processed. Additionally, while attention is focused on one object, shifts in attention to distracters are inhibited. These aspects of attention show major developmental change throughout infancy.

### **Subject**

In infants, attention is thought to change with age concurrently with changes in brain function. Several scientists interested in early cognitive development have proposed neurodevelopmental models of attention development based upon behavioral findings in human infants, integrated with findings related to changes in brain function from studies of non-human animals and human adults, or neuropsychological research on clinical populations.<sup>1,2,3,4,5,6,7</sup> Many of these models are influenced by Schiller's research<sup>8</sup> on eye movement systems in non-human primates. In infants from birth to two months of age, it is proposed that eye movements are primarily driven by a "reflexive system" largely under the influence of *primitive brain areas* located beneath the *cerebral cortex* (i.e., *subcortical*). Thus, eye movements and visual attention are generally reflexive in early infancy. Between three and six months of age, a voluntary orienting network becomes functionally mature. This network includes areas within the *parietal* and *temporal cortices* and the frontal eye fields and is involved in the ability to voluntarily shift visual attention from one stimulus to another.<sup>9,10</sup> From six months on, the anterior attention network (or executive attention system) becomes functional, as areas within the *prefrontal cortex* and the *anterior cingulate cortex* begin to play a significant role in maintaining visual attention while inhibiting shifts of attention to distracters.

### **Problems**

Infant visual attention and brain development are often studied using "marker tasks." These are behavioral tasks for which the brain areas involved have been firmly established. Johnson<sup>11</sup> has argued that marker tasks can be used to indirectly study brain

development in infants and children. However, Richards and colleagues<sup>12,13</sup> argue that there are several weaknesses to this approach and that the best solution is to apply direct measures of brain activity. Most of the major approaches to direct measurement of cortical activity (e.g., positron emission tomography, functional magnetic resonance imaging) cannot be used with human infant participants because of ethical and/or practical concerns. We describe a new technique to measure human infant brain activity directly.

### Research Context

Infant attention is measured in the laboratory using looking time, heart rate, and the electroencephalogram (EEG).<sup>14,15,16</sup> Briefly, infant heart rate shows a sustained decrease during periods of attention. This decrease in heart rate is triggered by activity within the brainstem. The EEG measures electrical activity that is produced in the brain with electrodes on the scalp. A common approach to research on perception and cognition is to identify *event-related potentials* (ERPs) in the EEG. ERPs are changes in EEG that are related to a specific event or task. Specific ERP components are identified; these show changes in electrical activity based upon experimental conditions. EEG and ERP data can be further analyzed with multivariate statistical modeling techniques, referred to as Equivalent Current Dipole (ECD) analysis, to determine which brain areas are the likely causes of ERPs measured on the scalp.<sup>15,16,17</sup> This provides a more direct measure of infant brain activity involved in attention.

### Key Research Questions

The key research questions addressed by this line of work are what areas of the brain are involved in infant attention, whether the areas involved in attention change across the course of infant development and, whether *electrophysiological* measures of attention are consistent with behavioral measures of attention. Ultimately, all of these questions relate to the need to learn more about brain-behavior relations in infancy.

### Recent Research Results

In infant ERP research, a component of the ERP labeled Negative central (Nc) has been found to be more active following presentation of salient stimuli and most likely related to attention.<sup>14,18,19</sup> Richards<sup>14</sup> found that the Nc component is greater in amplitude when heart rate indicates attention. In a follow-up study, Reynolds and Richards<sup>15</sup> found that the areas of the brain involved in the Nc component are located within the prefrontal cortex and the anterior cingulate. Remember that these are areas associated with the executive attention system. The Nc component has been found to increase in amplitude as the infant ages, indicating increased attention-related activity in the prefrontal cortex during infancy.<sup>14,20</sup> This parallels increased voluntary control of attention occurring in this age range.<sup>21</sup> Recently, we<sup>16</sup> designed a procedure that simultaneously measures behavioral responses and infant ERPs. Results showed that infants who prefer to look at a novel stimulus rather than a familiar one show greater Nc activity following novel stimulus presentations than familiar presentations. Those who do not demonstrate novelty preference also fail to demonstrate differences in Nc based upon novelty versus familiarity. Taken together, these findings show consistency between behavioral, heart rate and ERP correlates of infant attention.

### Research Gaps

Although the application of ECD analysis to infant ERP data represents a major step in measuring attention-related infant brain activity, there is still much room for progress. The parameters used in ECD analyses are based on adult anatomy (e.g., skull and scalp thickness). The infant skull is thinner than that of adults, and the fontanels and skull sutures are not yet completely fused. Richards<sup>22</sup> is currently developing a procedure for ECD analyses using parameters based upon the individual infant's skull and brain matter. However, further progress must be made in designing new procedures to simultaneously measure behavioral and electrophysiological correlates of infant attention. Ultimately, what is needed is a direct, non-invasive measure of infant brain activity that can be practically applied. Until these research gaps are addressed, our knowledge of infant brain activity and brain-behavior relations will remain constrained by methodological limitations.

### Conclusions

There is a rich history of behavioral research on the development of attention in infancy. Additionally, several scientists working in the area have proposed models of infant brain development, integrating behavioral findings from infant research with research on brain development in animals and adults.<sup>1,2,3,4,5,6,7</sup> While many of the models proposed by such scientists may accurately describe the progression of infant brain development in relation to attention, at present the models remain untested because of methodological limitations. However, major progress has been made, and we now know that there is consistency between commonly used behavioral, heart rate and electrophysiological correlates of infant attention.<sup>14,16</sup> We have made an initial step in identifying areas of the brain related to cognitive development by demonstrating that areas of the prefrontal cortex and the anterior cingulate are involved in infant attention.<sup>15</sup> Many questions remain unanswered and limitations unaddressed. We are confident that steady progress will continue in research on infant brain development and attention.

### Implications

One of the major implications of research on infant attention relates to attention deficit hyperactivity disorder (ADHD). It is currently estimated that ADHD affects from 5 to 10% of school-aged children.<sup>23</sup> Symptoms of ADHD include poor control of attention, inattentiveness, hyperactivity, poor impulse control and behavior management problems. Evidence indicates that the inattentive aspect of ADHD may be related to deficits in the voluntary orienting network, whereas the hyperactive aspect of ADHD may be related to a poorly functioning executive attention system.<sup>24</sup> The executive attention system involves the prefrontal cortex and anterior cingulate, areas identified as sources of attention-related cortical activity in our research on infant attention.<sup>15</sup> ADHD is typically not apparent in affected children until the school years. These children may be referred to health-care professionals for problems controlling their behavior in classroom settings. It would be ideal to have an earlier identification method for children at risk of developing ADHD. The promise of basic research on infant attention and brain development is the potential identification of atypical patterns of infant development that may predict later onset of ADHD.

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