Infant Attention Grows Up: The Emergence of a Developmental Cognitive Neuroscience Perspective

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Abstract

Visual attention has long been regarded as a tool for studying the development of basic cognitive skills in infancy and early childhood. However, over the past decade, the development of attention in early life has emerged as an important topic of research in its own right. This essay describes recent changes in the methods used to study attention in infancy, and in the nature of inferences about the early development of attention, as both research and theory in the area have become progressively integrated with models of attention from cognitive science and neuroscience.

Keywords

infancy; attention; development; individual differences; developmental cognitive neuroscience

The modern investigation of the development of attention in infancy and early childhood evolved from the work of Fantz and Berlyne, who, in the late 1950s, borrowed methods from ethology and comparative psychology in monitoring infants' visual fixations to various visual stimuli. Initially, investigators in the field were content to document infants' selective looking to various visual properties (e.g., color, brightness, visual patterns, contour, "complexity," and stimulus novelty). It was quickly recognized, however, that the presence of systematic visual preferences in infants implied discrimination of the preferred from the nonpreferred stimulus. Furthermore, if one allowed an infant to study a stimulus for some amount of time and then presented a novel one, careful measurement would reveal increased looking to the novel stimulus. This preference for novelty implied the presence of memory and—by logical extension—the occurrence of visual learning in the infant. Investigators readily seized upon these selective-looking techniques to reveal important facts about early sensory function (e.g., visual acuity, detection of color), perceptual processes (e.g., form and pattern perception), and other basic cognitive "products" (e.g., visual discrimination, short- and long-term memory, category formation) during the first years of life. As a result, infant visual attention was for the most part regarded and used as a tool for elucidating the development of various aspects of early cognitive development. The development of attention in infancy and early childhood, however, was largely overlooked as a topic of research in its own right.

ATTENTION AS A PRIMARY FOCUS OF DEVELOPMENTAL RESEARCH

Two trends that emerged in the 1980s led to the consideration of the development of attention as a primary focus of research per se. The first trend was for developmental psychologists to seek an integration of cognitive-developmental phenomena with models of cognitive function that had been developed within the field of cognitive science. As I note later, this represented the origin of interdisciplinary cross talk that has continued unabated to this day, as work in cognitive development has become increasingly intertwined with both cognitive science and cognitive neuroscience over the past decade. The second trend had its origin in a number of articles published in the early 1980s that reported that various measures of visual attention in infancy were modestly but significantly predictive of cognitive function later in childhood. Both trends suggested that a fundamental understanding of the development of attention in and of itself might be important, useful, and fruitful for many realms in the behavioral and biobehavioral sciences.

Early Theory: Infant Looking as Encoding

Many of the initial studies of selective looking in infants were guided primarily by Sokolov's comparator model, which held that attention is distributed to a stimulus as a function of the match between the stimulus and the internal representation ("engram") of it. According to this model, prolonged looking indicates a mismatch between the two (or a lack of an engram altogether); brief fixations imply that the stimulus has been represented accurately and completely. The comparator model was helpful in explaining why infants show a decline in looking to repetitive stimulus presentations (i.e., visual habituation), although the model itself was directly based on neither attentional theory nor

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mechanisms proposed in the literature on adult cognition.

In any case, the theoretical bias in initial work on this topic was to interpret individual and developmental changes in looking in terms of visual learning, or encoding. One program of work in our own laboratory at the University of Kansas involved a description of the developmental course of, and the stability of individual differences in, visual attention within the habituation paradigm. These initial studies suggested that the development of attention over the 1st year was primarily manifest in terms of changes in the duration of looking (Colombo & Mitchell, 1990); young infants (e.g., 3- and 4-month-olds) looked for prolonged periods, relative to older infants (e.g., 7- and 8-month-olds). Moreover, although there was wide variability within ages, individual differences in the duration of looking were moderately stable from one testing to another (Colombo, Mitchell, O'Brien, & Horowitz, 1987), at least within age categories.

In the comparator theory framework, the duration of infant looking could be interpreted in terms of how quickly an infant encoded a stimulus. Thus, the developmental course implied that infants got faster or more efficient at encoding as they got older, and the stability of individual differences implied that some individual infants encoded faster or more efficiently than others. This interpretation was supported by subsequent empirical evidence showing that infants with prolonged patterns of looking tended to perform less well than their shorter-looking counterparts on visual recognition tasks in which the amount of time to study stimuli was limited (e.g., Colombo, Mitchell, Coldren, & Freeseman, 1991). As a result, psychologists came to consider prolonged looking in infants as a reflection of slower processing, both across and within ages.

Theoretical Change: Infant Looking and the Cognitive Neuroscience of Attention

Researchers from a more cognitive neuroscience perspective, however, approached the study of attention either by using converging behavioral and cardiac indices of information processing or by adopting the use of tasks that had been shown, at least with adults, to be associated with those brain structures or pathways that control or mediate attention. A major contribution of this work was to demonstrate that infant looking represented a variety of attentional states and components, including orienting and engagement of attention, maintenance of attention, disengagement of attention, and shifting of attention (e.g., Johnson, Posner, & Rothbart, 1991).

This work had two important effects. The first was that it tempered an implicit claim of comparator theory—namely, that the infant is continuously and primarily engaged in active encoding while looking at a visual stimulus. Second, and more important, given that the components of attention identified within looking in human infants were analogous with those identified and documented within the realm of cognitive science and cognitive neuroscience, this research promoted the integration of developmental and contemporary cognitive approaches to visual attention.

In our own research program, we began to look for brain-based mechanisms to explain why prolonged look duration was associated with slower speed or efficiency of encoding, both across and within ages. Normally, adults and children encode visual stimuli efficiently, processing the overall configuration of a stimulus first and the finer details (i.e., local features) later. However, a number of projects from our laboratory indicated that infants with prolonged look durations were drawn toward, or persevered in, inspecting the smaller local visual features of visual stimuli, rather than the larger patterns or overall configurations (see Colombo & Janowsky, 1998, for a summary of this work). Interestingly, Orlian and Rose (1997) hinted at the possibility that longer looking was associated with better discrimination of visual stimuli that were differentiated by discrepancies in local elements or details. These results could be explained through a number of underlying mechanisms related to maturation of the lower-order visual pathways (see Colombo, 1995). However, they were also consistent with the possibility that infants who showed prolonged looking tended to become "stuck" on certain visual features, and unable to inhibit or disengage their attention to shift it elsewhere (see Hood, 1995). This type of deficit has been linked to mechanisms of visual attention that are mediated by frontal or parietal areas of the brain.

A number of recent studies have lent strong support to this latter interpretation. We (Frick, Colombo, & Saxon, 1999) assessed 3- and 4-month-olds' look duration, and then administered a series of tasks that measured the speed with which infants moved their eyes from a position at midline to a stimulus that appeared unexpectedly in the peripheral visual field. In half of such trials, a stimulus remained illuminated at midline; this forced the infants to disengage attention from the stimulus there in order to make an eye movement to the peripheral one. In the other half of the trials, the stimulus at midline was removed just prior to the appearance of the peripheral stimulus, so that disengagement of attention prior to making the appropriate eye movements was not necessary. The look durations recorded in the pretest, in which infants looked at different slides of visual stimuli, were correlated quite strongly ($r = +.62$) with the time it took for the infants to initiate eye movements when disengagement was necessary, but uncorrelated ($r = +.01$) when disengagement was not necessary. That is, infants' look duration was directly related to their ability to disengage from a visual stimulus. Jankowski and Rose (1997) also found evidence for the association between look duration and the disengagement of attention, as infants showing prolonged looking moved their gaze across regions of visual stimuli far less than their shorter-looking counterparts.

Two recent follow-up studies have approached the issue more directly. My colleagues and I (Colombo, Richman, Shaddy, Greenhoot, & Maikranz, 2001) measured infants' heart rate (HR) while they were looking at stimuli during a recognition memory task. While infants are looking at a visual stimulus, at least some part of that look coincides with a slowing (i.e., deceleration) of HR (see Fig. 1). During this deceleration, infants are less distractible and more engaged in information processing than during other phases of the look, when HR has not yet decelerated (orienting) and after HR has returned to baseline levels (attention termination). Thus, it is possible to use HR data to determine whether infants are actively engaged with a stimulus (Richards & Casey, 1990). Of most interest is the period of attention termination, during which infants' looking at the stimulus continues despite the fact that the HR deceleration has ended. Presumably, larger amounts of time spent in this phase should reflect relative difficulty with the disengagement of attention. We suspected that this kind of difficulty might be correlated with prolonged looking, and that it might explain the relationship between prolonged looking and poorer recognition performance; indeed, both suspicions were confirmed. Finally, Jankowski, Rose, and Feldman (2001) recently published an important study in this line of inquiry. They showed that by enticing long-looking infants to shift their fixations among multiple areas of a visual stimulus, they could eliminate the deficits in recognition performance that have often been observed for this group.

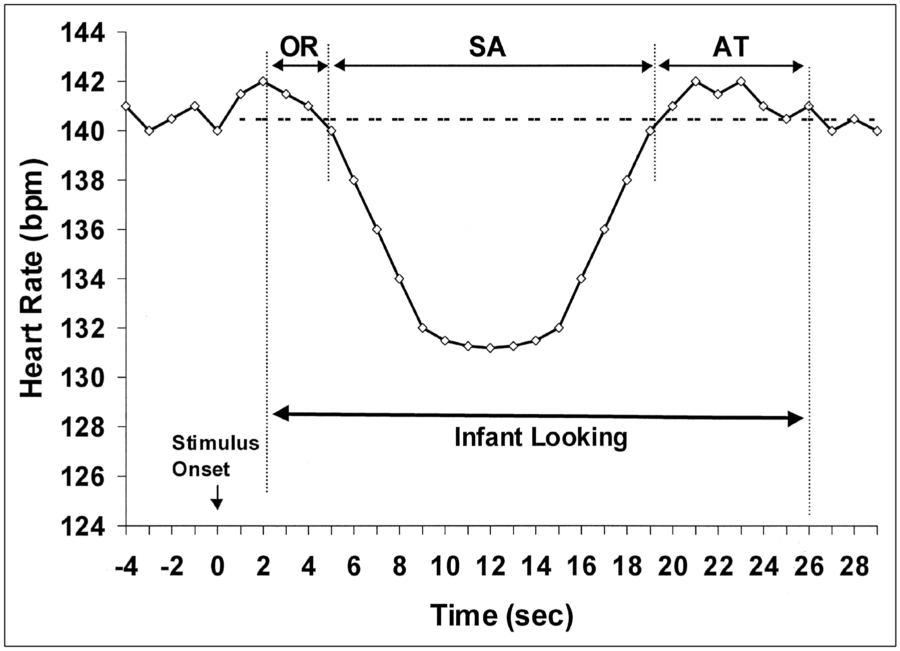

Fig. 1. Three phases of visual attention, as identified using the characteristic heart rate (HR) deceleration that occurs during infants' looking. The period during looking that precedes the attainment of a stable deceleration is called *orienting* (OR), and reflects how quickly the infant begins processing the stimulus. It is most closely identified with the construct of attentional engagement. *Sustained attention* (SA) is defined as the period of HR deceleration that typically occurs during infant looking, and is most closely identified with the encoding, or processing, of the stimulus. *Attention termination* (AT) refers to the period during which the look persists after the characteristic HR deceleration has ended. This phase is most closely identified with the construct of attentional disengagement. Adapted from Richards and Casey (1990); reprinted with permission from Colombo, Richman, Shaddy, Greenhoot, and Maikranz (2001).

Infant Looking: A Broader Developmental View

Overall, then, this research brought about a major change in the way in which individual and developmental differences in infant looking were viewed. At the same time that this evidence was being collected, however, research on the development of attention in primates and toddlers suggested that the development of looking was not accurately represented by a simple linear decline in duration across the entire range of infancy and early childhood. This prompted us to conduct a comprehensive review of the data on the development of look duration over a wider range of infancy than we have typically studied in our research on individual differences in attention (Colombo, Harlan, & Mitchell, 1999). This review yielded evidence for three fairly distinct phases over the 1st year: (a) a period from birth to 8 or 10 weeks during which look duration increases, (b) a period from 3 to 5 or 6 months of age when look duration declines, and (c) a period from 7 months onward during which looking duration plateaus or perhaps even gradually increases (see Fig. 2).

The initial increase is not well understood, although available theory and evidence point to the involvement of arousal and the emergence of alertness, likely mediated by brain pathways that link systems of arousal in the brain stem with higher areas of the cerebral cortex (Colombo, 2001). The decline in looking likely reflects changes in disengagement, although some aspects of object perception may also be involved. The plateau that begins later in the 1st year likely reflects the predominance of endogenous or sustained attention, which is more voluntary and task-driven than the other phases of attention. This latter period has received increased interest over the past several years in studies of distractibility, and the maintenance of attention in problem-solving and competitive contexts. Interest in the emergence of endogenous attention is likely to increase, as it reflects the emergence of components that are more colloquially regarded as attention (e.g., "attention span") by the general population, and that likely underpin the development of a number of cognitive and intellectual skills. It is also likely that research in this area of early attentional development may have clinical relevance.

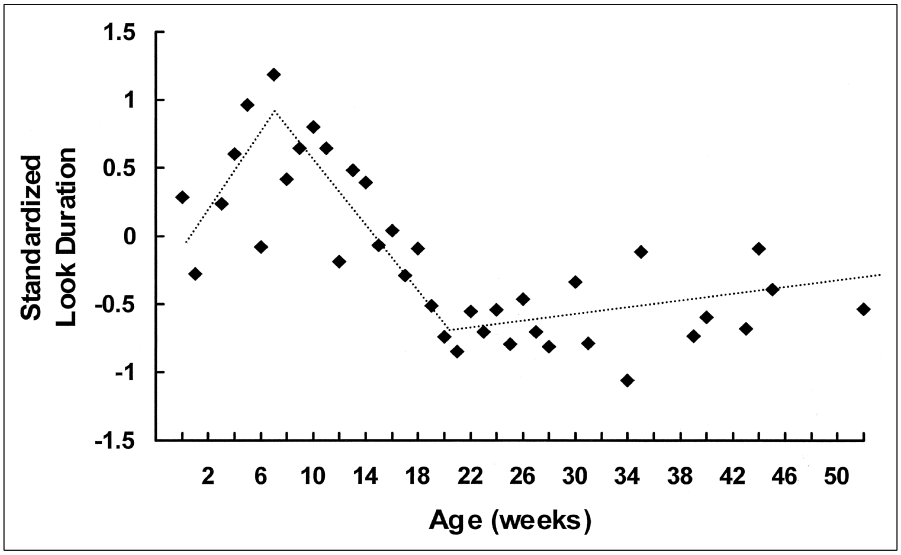

Fig. 2. The developmental course of look duration in infants, as suggested by a statistical review of the literature (Colombo, Harlan, & Mitchell, 1999). Forty-eight studies that included assessments of look duration from at least two ages were surveyed. Durations were standardized (*z* score) within each study, and a data point for each age was calculated by averaging the standardized scores across all studies that contributed data for that age. The dotted line represents the best-fitting regression line in each of three distinct phases observed during the 1st year (see the text).

CONCLUSIONS AND FUTURE DIRECTIONS

In the past decade, research on the development of attention in infancy has thus moved the field away from a focus based solely on comparator theory (i.e., simple encoding) and toward a perspective that is based on components derived from contemporary cognitive neuroscience models of attention (i.e., engagement, shifting, disengagement, object recognition and perception, and endogenous or sustained attention). Much of the extant research may need to be reinterpreted within this new framework (see Colombo, 2001). However, this change in perspective raises a host of new and critical issues to be addressed by research in this decade and those to follow. For example, differences among models of the development of disengagement in infancy will need to be resolved. Researchers will need to disentangle the relative roles and contributions of the development of the brain pathways that mediate attention to objects and to their locations in the visual field (both of which emerge during the first 6 months). The development of endogenous or sustained forms of attention, which are manifest in measures of distractibility and how attention is controlled under conditions in which multiple stimuli are present, is not particularly well described or well understood. These forms of attention emerge toward the end of the 1st year and are predominant through the preschool years, so studies across this age range are needed.

Among the larger issues to be investigated, however, is how the various components of visual attention, with their distinct and likely independent developmental courses, interact to produce the types of visual behavior seen during infancy. Another issue is how these different components in infancy contribute to the development of higher-order cognitive functions later in life; work on this question will undoubtedly need to delineate how environmental influences interact with (i.e., affect and are affected by) the infant's attentional skills at various points in development. These latter questions truly represent the integration of contemporary cognitive science with developmental psychology, and thus define a field of developmental cognitive neuroscience.

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Note

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