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The cascading development of visual attention in infancy: Learning to look and looking to learn

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Abstract

The development of visual attention in infancy is typically indexed by where and how long infants look, focusing on changes in alerting, orienting, or attentional control. However, visual attention and looking are both complex systems that are multiply determined. Moreover, infants' visual attention, looking, and learning are intimately connected. Infants *learn to look*, reflecting cascading effects of changes in attention, the visual system and motor control, as well as the information infants learn about the world around them. Furthermore infants' looking behavior provides the *input* infants use to perceive and learn about the world. Thus, infants *look to learn* about the world around them. A deeper understanding of development will be gained by appreciating the cascading effects of changes across these intertwined domains.

Keywords

Infancy; visual attention; looking; learning; developmental cascades

Historically, infants were conceived of as helpless, unable to interact effectively with the world, and subject to whatever experiences they encountered. Fantz's (1958) classic work changed this characterization. Specifically, Fantz showed that even very young infants will look more at some patterns than at others, and that we can understand infants' visual perception by measuring their looking. In other words, looking is a behavior that, from birth, infants use to interact with and learn about the world.

In the decades since Fantz's work, researchers have often described infants' changing looking behavior in terms of their developing visual attention. However, it is important to distinguish between looking behavior and visual attention, both of which are multiply determined, complex systems. Looking is an *overt behavior* that can be observed by recording the direction of gaze. It is controlled by cognitive processes such as memory and attention as well as by motor control over the head, neck, and eyes. Visual attention, in contrast, is a system of functions that allows people to select some information for processing and learning while ignoring or inhibiting other information (Luck & Vecera, 2002). These processes can occur without looking (i.e., covert attention), and attention may or may not be engaged during bouts of looking. The reliance on overt looking in the study of infant attention, therefore, has led to some imprecision in how visual attention is defined and understood in infancy.

Although looking behavior and visual attention are not precisely the same thing, they are intimately connected and are part of a developmental cascade that involves many processes including perception and learning. Young infants often look at what they can actually see and what automatically captures their attention, reflecting bottom-up processes determined by the maturation of the visual system and subcortical attentional control. Across development, infants' looking reflects cortical development of attention systems, development of cognitive and motor abilities, and the effect of experience and knowledge on infants' looking behavior. As a result, infants' have more voluntary control over where they look and their looking is related to their current goals and experience. The point is that it is important to acknowledge both the differences between looking and visual attention and how they are connected across development.

Visual attention in infancy

Inspired by Posner and Petersen's (Petersen & Posner, 2012; 1990) influential model of attention, researchers have examined developmental changes in infants' *arousal*, *orienting*, and *control* of attention. Arousal broadly refers to the alerting and sustaining of attention. Orienting involves the processes that prioritize and select some information for further processing. Control of attention includes top-down forces, including task goals, on the focus of attention. In general, research has revealed different developmental trajectories for these different aspects of attention. For example, attentional states (related to the arousal network) developing over the first postnatal weeks, orienting undergoing change in the first 6 months, and attentional control shifting to more goal oriented, voluntary control late in the first year (see Oakes, 2023 for a summary).

Typically, research has described the development of different aspects of visual attention in isolation, focusing on arousal *or* orienting *or* control. However, *attending* requires a combination of all three. As an example, consider a study by Kwon et al. (2016) using stimulus arrays like those shown in Figure 1 with infants from US middle-class families. When shown these arrays, 6- and 8-month-old infants looked first at the face, but, somewhat surprisingly, 4-month-old infants looked first at the most physically salient item in the array (which was never the face). At all ages, infants looked longest at the face, suggesting that although there was a developmental shift in where infants looked first, at all ages infants preferred the faces as indicated by where they maintained their attentional focus.

What do these changes in overt looking behavior reveal about the development of attention? Do they reflect development of infants' attentional state or how ready they are to respond? Perhaps these changes reflect development in infants' ability to orient or their control of attention. Another possibility is that because older infants have more experience with faces, the faces in the arrays are more meaningful and therefore more effective at capturing their attention. What infants look at first must reflect all these factors, and the change we observed certainly indicated development of a combination of alerting, orienting, and attentional control. Moreover, infants' developing ability to shift their gaze in these contexts also reflects their developing abilities to control their head, neck, and eye movements, as well as their abilities to actually see the items, perceive and recognize them, and relate them to their previous experience. The point is that observations of developmental

change in looking behavior cannot be reduced to reflecting the development of a single attentional function, but rather are best understood as reflecting the development of the entire attentional system in the context of a developing whole child.

Learning to look

How do infants learn to look? The image in Figure 2 is taken from a camera positioned to capture the world from the infants' point-of-view. This image shows what elements are in the infant's field of view, not which element the infant actually looks at. It is likely that when confronted with this scene, infants of different ages will look at different things, in part due to changes in visual acuity (Dobson & Teller, 1978) and the emergence of cortical attentional control (M. H. Johnson, 1994). As a result of poor visual acuity, poor motor control over eye movements and the head and neck, as well as subcortical control of attention, newborn infants preferentially look at faces and moving stimuli, and the edges of objects (S. P. Johnson, 2013). Thus very young infants would look at those features of scenes such as this one.

Across age, however, where infants look will change. Studies using a variety of stimuli and procedures suggest a developmental shift from looking early in infancy being driven more by stimulus properties, such as physical salience, whereas looking later in infancy also reflecting "top down" factors such as the infants' goals, familiarity, the social significance of the stimuli, and so on (Colombo, 2001; Oakes, 2023). We have found developmental patterns supporting this conclusion when infants are shown arrays of objects (Kwon et al., 2016) or "natural" scenes–photographs of kitchens, lakes, restaurants, and so on (Pomaranski et al., 2021). From this literature we would predict that younger infants who viewed this scene would likely look at the most physically salient part of the image, but older infants would focus more at the most meaningful regions, such as objects and faces of the people. Moreover, where infants look at the faces likely change as their looking shifts from looking at edges and areas of high contrast to looking at eyes and mouths as a way of recognizing individuals, identifying emotions, and learning language.

Recently, this development for where and how long infants look has been recognized to reflect *developmental cascades* (Amso & Scerif, 2015; Oakes & Rakison, 2019). In other words, changes at one point in time (and in multiple domains), set the stage for developmental changes at later points in time. As a result, we understand that changes in looking reflect not only changes in visual acuity and cortical control of attentional focus, but also changes in motor development, previous learning, social interactions, and more. The developing cascade of infants' looking is schematically presented in Figure 3. The left column describes some developing abilities that influence where and how long infants look. The right column represents the infants' behavior and the resulting input that shapes the development of their looking. These are not exhaustive lists, but some illustrative examples to demonstrate the development of this system.

For example, changes in oculomotor control as well as dramatic changes in head, neck, and trunk control (Adolph & Berger, 2006) allow developmental changes in infants' abilities to maintain eye contact (Akhtar & Gernsbacher, 2008), exhibit anticipatory looks (Haith et

al., 1988), and disengage attention (Hood, 1995). As infants become focused on the actions others perform on objects, they may shift from looking at the faces in the scene to looking at the hands (Fausey et al., 2016). Infants' abilities to manipulate objects and move their bodies also contribute to the development of looking behavior. Smith and colleagues (2018) examined the view from video cameras mounted on infants' heads as they go through their daily lives and found that across development the specific objects and views of objects change as infants become able to bring objects into view, move to see objects not in view, and manipulate objects to see them from multiple perspectives. Changes in infants' manipulation and visual-manual exploration of objects support infants' visual attention to and perception of objects and object properties (Needham et al., 2002; Soska et al., 2010).

Moreover, infants' looking also reflects their past experience and what they have learned about looking. Young infants' looking at edges, faces, and areas of high contrast stimulates their visual system and promotes the development of visual attention (Amso & Scerif, 2015). However, what infants look at also creates biases that will influence what they learn about the world. For example, as a result of their initial visual biases combined with the prevalence of faces in their environment, infants look at faces more than any other stimulus. Infants' experience looking at faces, and their resulting attentional and perceptual skills related to face processing, will influence whether infants look at faces, which faces they will select, and so on (Markant & Scott, 2018). The point is that infants learn to look, and that learning reflects changes in multiple systems.

Considering these cascades also can provide new understanding into individual differences in looking. Decades of research has revealed that individual differences in infants' looking predict later outcomes, such as academic achievement and language development (Bornstein et al., 2013; Rose et al., 2012). Often such findings are assumed to describe stable individual differences in information-processing. The cascade in Figure 3 suggests that individual differences in looking may reflect variations in visual abilities, cortical attentional control, motor abilities, experience, or many other factors.

Looking to learn

Infants also look to learn. As infants' visual exploration of the world changes due to developmental changes in visual ability, attentional control, motor development, and so on, there are changes in what and how infants learn about the visual world. Thus, just as with infants' learning to look, developments in infants' looking behavior have cascading effects on their learning.

In some sense, the idea that infants learn from looking is the foundation of the modern study of infant cognition. Procedures such as visual habituation and novelty preference are based on the assumption that infants learn about stimuli by looking at them and that changes in looking reflect that learning (Colombo & Mitchell, 2009; Oakes, 2010). In these procedures infants are first familiarized with a stimulus or set of stimuli, which are shown either until they habituate (i.e., their looking time decreases) or for a fixed period of time. It is assumed that during this phase infants learn and form a representation of the familiar stimulus as they look at it. Infants then are presented with one or more novel stimuli during a test phase.

Infants increase their looking to these novel stimuli demonstrating their ability to perceive those stimuli, discriminate them from the now-familiar stimuli, recognize them as novel, and so on.

Clearly, in these procedures looking behavior reflects a complex combination of multiple processes, including learning, yielding some imprecision in the understanding between the distinction between learning and looking. As an example, consider the evidence that infants shift from preferring familiar items to preferring novel items as a function of the duration of their looking (Hunter et al., 1982) or number of trials (Roder et al., 2000). Although it is tempting to draw conclusions that these fluctuations from familiarity to novelty preference solely reflect differences in *learning*, it is clear that this shift is influenced by learning as well as a number of other factors that contribute to infants' looking.

Infants do learn from their looking, however. What infants look at provides the input that they use to acquire knowledge and develop new insight and skills (Oakes, 2017; Smith et al., 2018). Moreover, changes in infants' looking behavior change what they learn. In Figure 2, if an infant looks at edges and areas of contrast of an object, those features will be learned. However, the infant can learn the experimenters' identities or emotional expression by looking at their faces, and can learn about objects by focusing on the experimenters' hands. Development in other areas also contribute to these changes. For example, infants' abilities to bring objects into view, move to objects of interest, and manually explore objects all change the views infants have of the world, creating new input for learning (Smith et al., 2018). Older and younger infants learn different things because they look at different features of the visual world, a phenomenon Smith and colleagues (2018) have described as the child's own development creating a curriculum for what they can learn from looking.

Studies using eye tracking methods in the lab have allowed increased precision in understanding the connection between looking and learning. S. P. Johnson et al. (2004), for example, found that where infants looked during habituation to the classic rod-and-box stimulus was related to whether or not they learned that the pieces of the rod were connected. That is, if infants mostly looked at the rod, they learned about the rod; if they mostly looked at the box they did not learn about the rod. In other studies, the proportion of time infants spent looking at certain facial features during habituation was related to whether they discriminated between familiar and novel faces (Amso et al., 2010; Gaither et al., 2012). Thus, not only is looking important for learning, but *how* infants distributed their looking was related to whether or not they learned the familiar face. Although these results are not necessarily surprising — after all, it is hard to learn about something you do not look at —they demonstrate the direct connection between what infants look at and what they learn about.

Research on infants' visual short-term memory (VSTM) also has shown a relation between infants' looking and what they learn in-the-moment (Beckner et al., 2020; Cantrell et al., 2019; Ross-Sheehy & Eschman, 2019). These studies used a one-shot change detection task (see Figure 4) with US infants from middle-class families. Infants were shown an array of shapes for a brief sample period (500–1000 ms), followed by a brief (300–500 ms) retention delay with a blank screen, and finally a test period with an array of shapes in which one

item changed color from the initial sample. If infants remembered the color of that item from the sample period, they should look longer at the changed item than at the non-changed item(s). When 5- to 6-month-old infants actually looked at the to-be-changed item during the initial sample period (before the change occurred), they detected the change in that item, suggesting they learned the color of the item they looked at (Cantrell et al., 2019; Ross-Sheehy & Eschman, 2019). However, looking at an item during the sample period did not help 4-month-old infants recognize the change in color of that item, suggesting they apparently did *not* learn from their looking (Beckner et al., 2020). Of course, this does not mean that 4-month-old infants never learn from looking, but it does indicate development between 4 and 6 months in infants' ability to learn from looking at a briefly presented array of colored shapes.

What infants learn from looking also will have a cascading effect on their subsequent looking and learning. For example, infants' looking at the objects and people allows them to form representations and expectations about those people and objects that contribute to top-down, or more cortically determined, voluntary control of attention. Infants' preferences to look at novel, unexpected, or impossible objects and events, for example, is shaped by their experiences and representations of familiar, expected, and possible objects and events. Infants develop biases to attend to people who look like the people around them (Markant & Scott, 2018), and infants with and without pets form different biases for looking at animals (Hurley & Oakes, 2015). All of these emerging and changing abilities influence infants' looking behavior and ultimately what they learn from that looking behavior.

Conclusions

Infants' looking behavior and visual attention are inextricably connected and part of a complex system that influences and is influenced by many other systems. Development in each of these domains influences the other, and both are shaped by visual abilities, cortical maturation, motor development, experience and learning, and much more. The discovery that infants' looking is systematically related to their visual, perceptual, and cognitive processes has been extremely important for the field of infant development. However, looking should not be considered simply as a reflection of those other cognitive processes, but rather as an active part of cognitive development. Not only do changes in looking reflect developmental processes, but those changes have cascading effects on the development of visual attention and learning. Because how long and where infants look determines the input for development, changes in what infants can see, how they direct their attention, and their interpretation of the visual input determines what infants learn about the visual world. As we move forward, a deeper understanding will be gained by considering these systems, rather than focusing on abilities in isolation, and by examining the cascading effects across these domains of development.

Acknowledgments and endnotes

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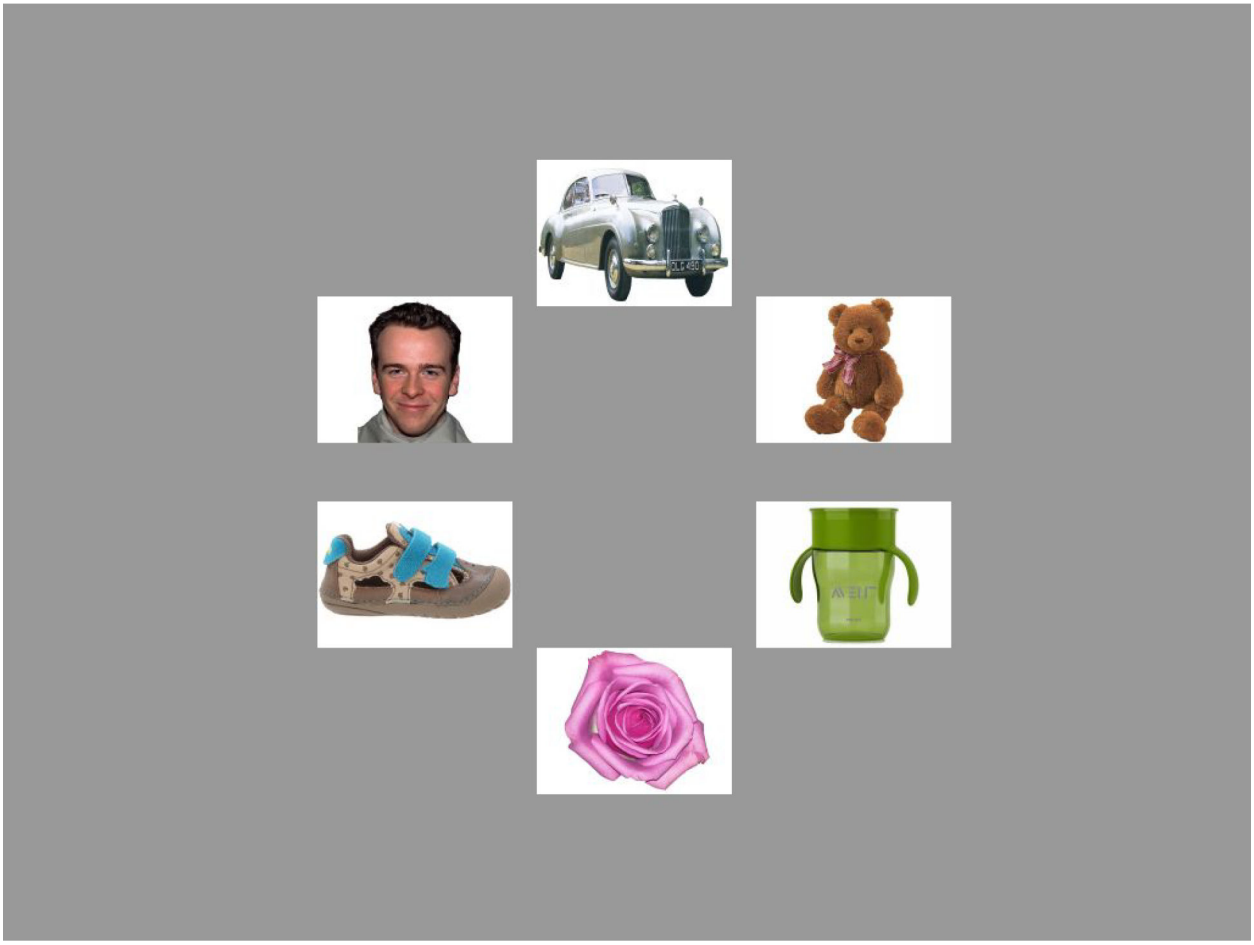

Figure 1.
An example of a stimulus array used by Kwon et al. (2016). The development of visual search in infancy: Attention to faces versus salience. *Developmental Psychology*, *52*(4), 537–555.

Figure 2.
A snapshot of the visual world from the infants' perspective.

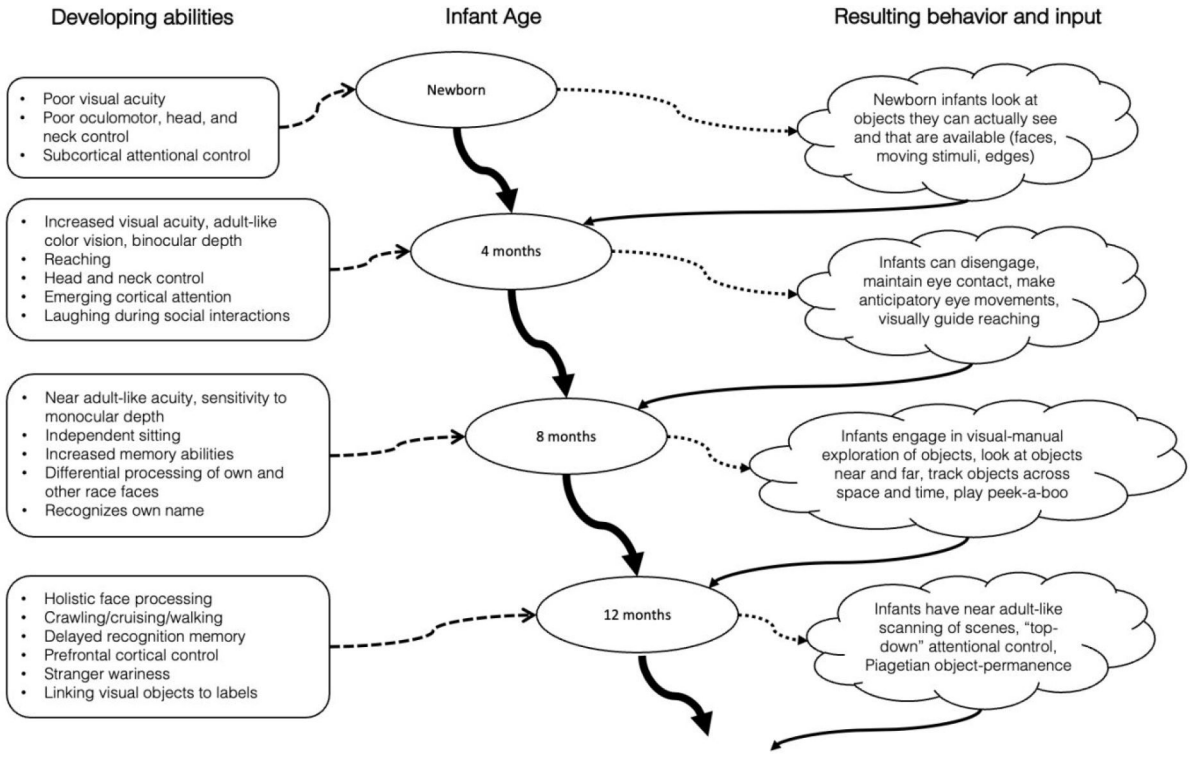

Figure 3.
A schematic illustration of the developmental cascade of looking behavior in infancy.

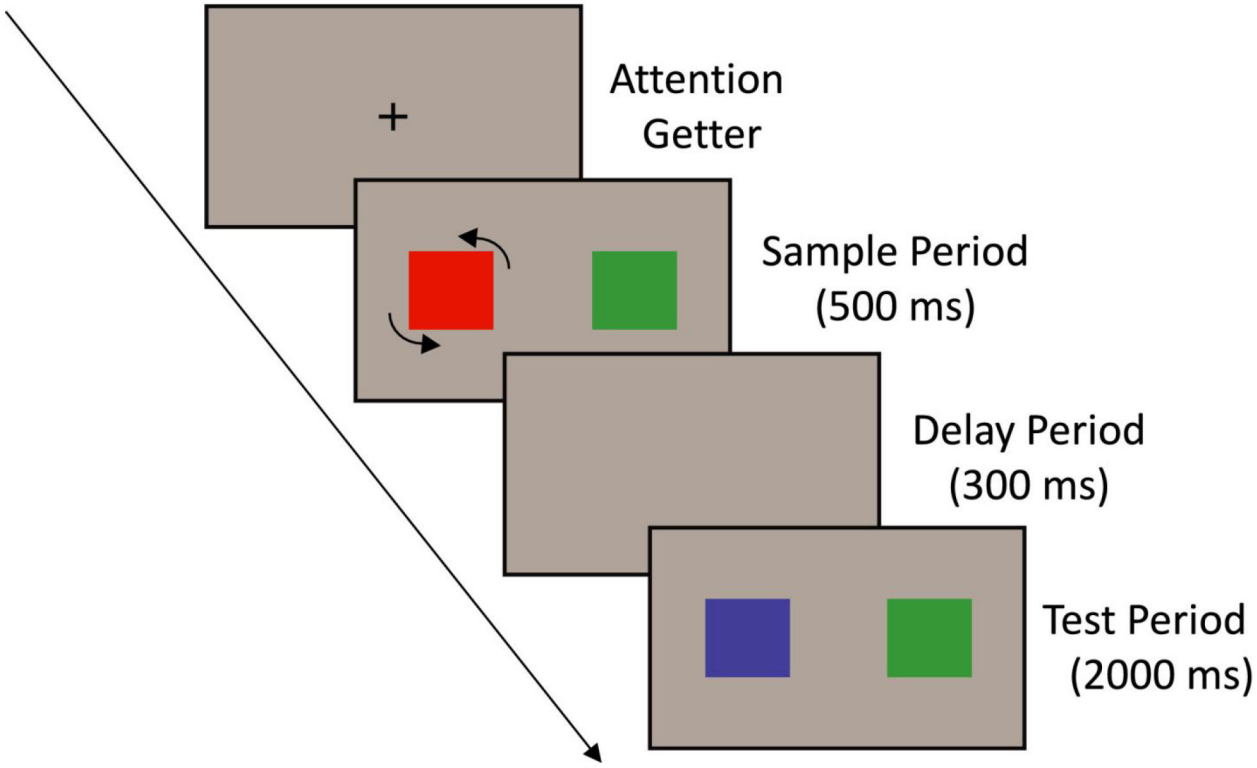

Figure 4.

An example of a “one-shot” change detection task used to study visual short-term memory (VSTM) in infants. From Beckner, A. G., Cantrell, L. M., DeBolt, M. C., Martinez, M., Luck, S. J., & Oakes, L. M. (2020). Visual short-term memory for overtly attended objects during infancy. In *Infancy* (Vol. 25, Issue 3, pp. 347–370). https://doi.org/10.1111/infa.12332 Copyright © Wiley, reprinted with permission.