Using Eye Tracking to Understand Infants' Attentional Bias for Faces

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ABSTRACT—***Infants have a natural tendency to look at adults' faces, possibly to help initiate vital interactions with caregivers during sensitive periods of development. Recent studies using eye-tracking technologies have identified the mechanisms that underlie infants' capacity to orient and hold attention on faces. These studies have shown that the bias for faces is weak in young infants, but becomes more robust and resistant to distraction during the second half of the 1st year. This development is apparently related to more general changes in infants' attention and control of eye movement. As a tractable and reproducible aspect of infant behavior, the attention bias for faces can be used to examine the neural correlates of attention and may be a way to monitor early neurodevelopment in infants.***

KEYWORDS—*eye tracking; infants; cognition; attention; face perception*

A spontaneous tendency to look at others' faces is a hallmark of infants' behavior and an important cognitive adaptation that facilitates infants' engagement in vital facial interactions with caregivers during sensitive periods of development (1). Beginning in a rudimentary form soon after birth, this attention bias may arise from an inherent tuning of infants' visual system to patterns that resemble the human face (2). Initially, researchers studied the bias by observing infants' head and eye movements, but in the past decade, with the increased availability of infant-friendly eye-tracking technologies, infants' attention can be studied at greater levels of spatial and temporal detail. Researchers can now examine such questions as whether infants find faces amid many objects and how the bias for faces is manifested in interactions with adults.

Infants' attention can be divided into attention orienting and attention holding (3–5). In the former, infants orient their eyes to a target, such as a face; in the latter, infants keep their eyes locked to the target so they can analyze it in detail. A similar distinction is made in computer vision literature (6) where the localization of a face in a scene (i.e., isolation of the face from the background and alignment with a standard template) is separate from the subsequent "measurement" of the distinguishing characteristics of the face (i.e., identification of an individual's identity, facial expression, gaze direction, etc.). Hence, orienting and holding attention are important prerequisites for processing various social cues from faces, and for making eye contact and interacting with faces in other ways. However, studies of gaze orienting and holding as attentional operations provide no information about how infants recognize specific facial attributes and communicative cues (e.g., identity, expression).

In this article, I briefly review eye-tracking studies that examine how infants' spontaneous bias to look at faces is manifested in attention orienting and holding. Although these studies partially support the long-held hypothesis of infants' biased attention to faces, they also show that this bias changes and becomes more robust with development, and that the changes are driven by more general changes in infants' visual and attentional abilities.

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BIAS IN ATTENTION ORIENTING

When infants (or other people) explore a visual scene, they do so through a series of saccadic eye movements that bring the limited area of sharp foveal vision to specific regions of the scene. According to the prevailing models of visual attention (7), eye movements during free viewing are directed primarily toward physically salient areas in the scene (e.g., areas with high contrast in color, intensity, or orientation), so the first gaze shift is always directed toward the most salient location. After this location has been explored, it is suppressed and gaze shifts to the second most salient location, followed by other locations in order of saliency. Hence, the observer's first look is directed to a face if the face pops out from the surrounding objects because of salient cues (e.g., the contrast of the sclera and iris in the eyes [8], or teeth and upturned mouth corners [9]), or because the human visual system is sensitive to the basic geometry of the face and prioritizes this combination of features over other cues (10).

Sensitivity to the basic geometry of faces is thought to exist at birth (2), but it has been unclear whether this sensitivity is robust enough to lead infants to select faces as the targets of their first gaze shift over other visual objects that are present in complex scenes. To test this possibility, several recent studies have examined whether infants' first gaze shifts are directed toward faces when viewing stimulus arrays consisting of a face and three to five other objects, or whether first gaze shifts are unbiased—so faces are selected as targets of first gaze shifts as often as other visual objects (5, 8, 11).

In two studies of 6-month-olds, infants' initial gazes were biased: Their first looks were directed toward faces about 50% of the time (the predicted level based on unbiased visual orienting was 17%; 5, 8). Moreover, they were biased in favor of faces even when faces were not the most salient targets in the scene in terms of their color, luminance, or contour (8). While these results are consistent with an attention bias toward faces in infants, other results suggest that the bias cannot be interpreted as a specific tuning of the infants' visual system to the basic geometry of faces. In essence, the bias was also found for inverted faces (5) and, to some extent, for pictures of body parts and animals (8). Furthermore, at 6 months, the mechanisms biasing attention to faces may still depend disproportionally on the presence of specific cues, such as color; a study of 3- to 6-month-olds did not reveal this bias when faces were presented as shades of gray (11).

While biased orienting to faces appears rudimentary at 6 months, this bias becomes more robust with development. In a study that failed to find evidence for biased orienting to faces in 3- and 6-month-olds (11), adults were biased when tested with the same paradigm. Similarly, in a study of observers of a range of ages, the proportion of trials in which infants fixated on the face during the first second of viewing the scene increased from 15% at 4 months to 50% by 12 months, and then to almost 90% by 24 years (12).

These age-related changes in attentional bias for faces may reflect specific developmental changes in sensitivity to faces, such as strengthening of the perceptual template for the basic geometry of faces (6), or gradual increases in the motivation to look at faces as a source of social information (13). However, the age-related changes in the localization of faces may also reflect more general developmental changes in visual function and attentional abilities (12, 13). These changes relate to increased sensitivity to visual features, such as color, orientation, and intensity, and increased use of these cues in the guidance of eye movements toward salient visual objects (12), as well as age-functional maturation of frontoparietal attention networks (14), important for the capacity to selectively attend to specific visual targets while suppressing other, interfering inputs (12, 15).

In a study that supports the role of developmental changes in visual abilities in the attention bias for faces, infants were less likely to benefit from color, intensity, and orientation contrasts in localizing faces than older children and adults (12). Also, the correspondence between infants' gaze patterns for a given scene (i.e., eye position in *xy* coordinates) and the physical salience values for the same scene (i.e., intensity, color, and orientation values for each *xy* coordinate) increased with age (12), suggesting developmental changes in sensitivity to visual features. Support for age-related changes in attention networks, in turn, comes from results showing that the average duration of visual fixations, which is a proxy of the ability to keep attention in a stationary position (16), correlates positively with the attentional bias toward faces (12). Similarly, age-related improvements in the general abilities to localize visual targets among other objects (e.g., a discrepantly oriented bar or a moving bar in an array of similar bars) mediate age-related increases in total looking time toward faces in complex dynamic scenes (15; Figure 1).

BIAS IN ATTENTION HOLDING

After infants fixate on an object, they sometimes look at it for a long period, inspecting its distinguishing characteristics carefully. How long they look is thought to depend on the complexity of the object (3), and may directly reflect the time it takes to construct an internal representation or trace of the external stimulus (17). Instead of a single fixation, prolonged holding of attention on an object is likely to consist of many separate fixations that span different subregions of the object. Eye-tracking research can produce a detailed characterization of the spatial distribution of these fixations (18), but such analyses are not typically performed in studies of infants because of the limits of the spatial resolution of eye-tracking technologies when used with participants who do not sit still (15).

Attention holding in infants can be quantified by calculating the cumulative duration of individual looks at the target area. This duration of total looks is not reliably longer for faces than for other visual objects in 3-month-olds, but most studies using

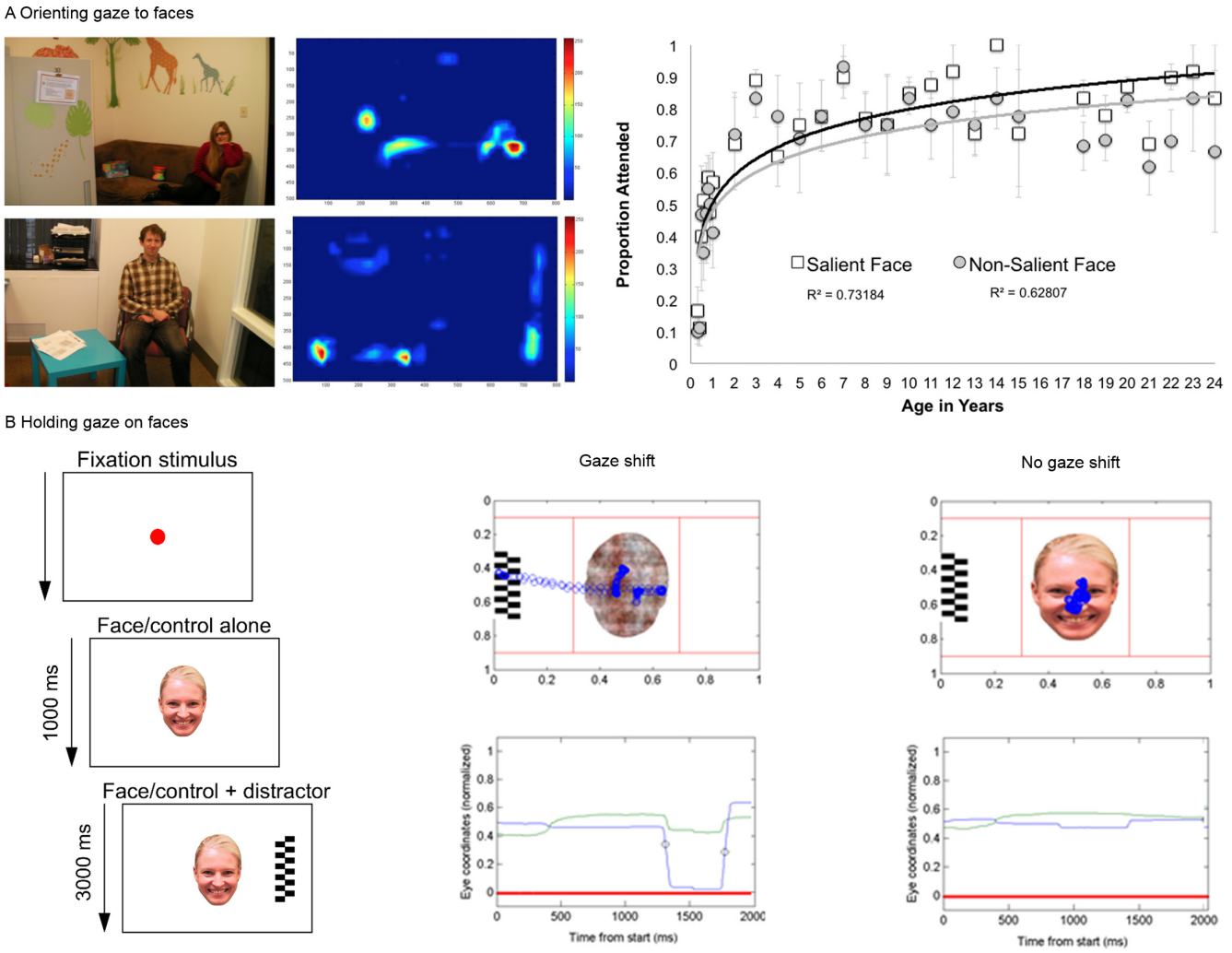

Figure 1. Bias for faces in gaze orienting and holding. *Upper left*: A paradigm testing infants' orientation to faces in cluttered scenes where faces were either the most salient or not the most salient. *Upper right*: Age-related increase in orientation to faces (especially when faces were the most salient elements of the scene), as shown by increased proportions of trials in which the observer fixated the face at least once during the first second of the image viewing. (*Note*. The figures in the upper row are reproduced from Amso et al. [12] under the terms of the creative commons attribute license.) *Lower left*: Face-distractor competition paradigm. Participants fixating a face stimulus in the center of the screen were presented with a lateral distractor to the left or to the right. *Middle*: A trial with a rapid gaze shift from the stimulus in the center to the lateral distractor (the gaze shift is seen as an abrupt change in *x* coordinates of the gaze). *Lower right*: An example of a trial in which the gaze holds in the central stimulus, and the saccade to the lateral stimulus is suppressed. (*Note*. Data reproduced from Leppänen et al. [21].)

this measure have shown reliable bias for faces in 6-month-olds and older infants (4, 5, 8). In an extension of the work examining infants' attention to faces displayed on computer screens, infants' gaze behavior was recorded by head-mounted eye trackers while infants were carried in an office hallway (19). Infants maintained gaze on people 45% of the time people were in view; adults (i.e., the mothers carrying the infants) maintained gaze 18% of the time.

When infants are fixating on a face, they may actively maintain their attention on this stimulus by filtering out other, competing inputs. We see this phenomenon in studies showing that attention to a face in the center of a visual display momentarily suppresses reflexive saccades to other competing stimuli in the visual periphery (20, 21). Present at 3 months (22), the phenomenon was interpreted initially as difficulty disengaging from a stimulus with social or emotional signal value instead of active attention (23). In young infants, it is challenging to distinguish obligatory looking resulting from a difficulty to disengage from more active prioritization of attention. But because obligatory fixations are typically observed at around 1 and 2 months, and the capacity to disengage and shift spatial attention from one stimulus to another is well developed by 6 months (24), the most likely interpretation of maintaining attention on faces, especially in older infants, is that this bias involves active suppression of responses to other distracting stimuli. A similar interpretation has been proposed for increases in sustained attention to patterned stimuli in infants between 6 and 12 months (17).

The tendency to actively maintain gaze on faces strengthens during the second half of the 1st year. At this age, infants viewing complex scenes begin to fixate longer on faces than on salient competing stimuli (13). Similarly, the tendency to hold attention on faces upon presentation of distracting stimuli increases significantly between 5 and 7 months, but does not change further between 7 and 11 months (20). In addition to becoming stronger, the bias to hold attention on faces may also become more selective over development, leading to increased prioritization of attention to faces that are more complex, novel, and informative. For example, 5-month-olds hold attention no differently for neutral and emotional faces, or the differences between these conditions are smaller than in 7-month-olds, who hold attention more selectively for faces displaying salient emotions such as fear (17, 20).

The strengthening of the attentional hold for faces during the second half of the 1st year may relate to emerging functionality of prefrontal systems involved in active control of attention. In studies of nonhuman primates and human adults, face-sensitive areas in the occipital–temporal cortex feed forward to prefrontal areas (25), and the activation of a distinct population of fixation neurons in the frontal eye fields and superior colliculus is important for maintaining fixation on a stimulus and inhibiting generation of saccades (26). Prefrontal control networks may also maintain stationary attentional focus through top-down modulation of visual excitability, resulting in selective enhancement of responses to the target stimulus and reducing responses to competing stimuli (27). The possibility that these systems change during the second half of the 1st year is supported by brain imaging studies showing increased metabolic activity in prefrontal areas at this age (28) and changes in infants' behavior that suggest reduced responsiveness to visual distraction.

Infants may hold attention on faces, especially faces making eye contact, to derive communicative cues, such as facial expressions or shifts of gaze that cue attention to an object in the environment (29). To use these cues effectively, infants must not just orient to the source of the communicative act (i.e., the face), but also look away from the face to the cued object. The tendency to hold attention on faces might interfere with the gaze disengagement and, consequently, prevent optimal use of communicative cues. However, this does not seem to be the case because 6-month-olds can release attention holding and disengage from an adult's face when the adult uses her gaze to signal the infant to look at an object (30). This result further supports the hypothesis that in infants, holding attention on faces is voluntary rather than obligatory, because infants apparently can terminate fixating on the face when a relevant signal is given.

SUMMARY AND LOOKING AHEAD

New eye-tracking technologies have led to renewed interest in infants' attentional bias for faces, enabling researchers to obtain increasingly detailed spatial and temporal information about this bias. The evidence I reviewed in this article shows that biased orienting to faces in complex scenes is absent or weak in 3-month-olds, but becomes more reliable during the second half of the 1st year. Biased holding of attention on faces is present at 3 months, but this tendency may be mediated initially by immaturity of the mechanisms involved in gaze disengagement, and more active prioritization of faces may not emerge before 6 months. Hence, a clear shift in both abilities apparently occurs during the second half of the 1st year, when infants begin to localize faces reliably and look at faces longer than at other salient aspects of scenes, and when attention to faces becomes more resistant to distraction. This developmental shift may relate to more general improvements in attention skills at this age, originating from functional development of those frontoparietal networks that underlie control of eye movement and voluntary prioritization of attention to sensory inputs.

Two areas merit further study. First, as highly reproducible and tractable aspect of infants' behavior, the bias for faces may be stable enough to lend itself to a detailed analysis of neural correlates, and may provide insights into the mechanisms that mediate attention orienting, maintenance, and termination in the developing brain. Second, infants' biases for faces may inform translational research aimed at developing novel markers of early childhood development. The bias to orient to faces is regarded as a cognitive adaptation that is functionally significant for early neurodevelopment and social behavior (2). A lack of this bias in infants may predict increased risk for autism (18), and tests are being developed to detect the absence of age-typical attentional biases in infants in pediatric practice (31). An important and potentially realizable prerequisite for developing such technologies is to characterize the typical developmental course of face perception in a sufficiently large number of infants, and to demonstrate that the strength of the attentional bias for faces can be tested reliably in individual infants.

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