Face detection in infants and adults: Effects of orientation and color

Elizabeth A. Simpson [a,*], Sarah E. Maylott [a], Kyla Leonard [a,b], Roberto J. Lazo [a], Krisztina V. Jakobsen [c]

[a] Department of Psychology, University of Miami, Coral Gables, FL 33124, USA
[b] Department of Psychology, Northern Illinois University, DeKalb, IL 60115, USA
[c] Department of Psychology, James Madison University, Harrisonburg, VA 22807, USA

ARTICLE INFO

ABSTRACT

Humans rapidly locate and recognize human faces, even in complex environments. In the current study, we explored some of the social and perceptual features of faces that may contribute to this ability. We measured infant and adult attention to complex, heterogeneous image arrays containing human and animal faces. Arrays were upright or inverted 180° and in color or grayscale. Infants, aged 3–5 months ($n = 51$) and 10–11 months ($n = 34$), viewed 6-item arrays (Experiment 1), whereas adults ($n = 120$) searched 64-item arrays (Experiment 2). We found that 3- to 5-month-olds already displayed strong own-species biases in face detection—in attention capture, attention holding, and overall detection—suggesting a surprisingly early specialization for human face detection. Furthermore, this remarkable ability was robust, evident even when color and orientation were disrupted, and grew stronger with age. Interestingly, infants' face detection was reduced by low-level manipulations in a species-specific way, negatively affecting only animal face detection but not affecting human face detection. In contrast, adults' face detection efficiency was equally reduced by low-level manipulations across species, suggesting potential age differences in own-species face detection. For infants, social relevance (species) may play a more important role than low-level perceptual features, ensuring that infants attend to, connect with, and learn from the people around them.

* Corresponding author.
  E-mail address: simpsone@miami.edu (E.A. Simpson).

Efficient human face detection during infancy may reflect the uniqueness of own-species faces as a category, perhaps due to their social relevance.

Introduction

Like adults, infants readily detect human faces in complex visual environments (Frank, Amso, & Johnson, 2014; Gliga, Elsabbagh, Andravizou, & Johnson, 2009; Kelly, Duarte, Meary, Bindemann, & Pascalis, 2019). Quickly locating faces and identifying faces are foundational social capacities (Mayer, Vuong, & Thornton, 2015; Simion & Di Giorgio, 2015). Infants' attention bias to faces may be a useful marker of healthy infant social development (Peltola, Yrttiaho, & Leppänen, 2018). For example, infants later diagnosed with autism spectrum disorder (ASD) display reduced attention to faces during the first 2–6 months after birth (Bradshaw et al., 2019; Jones & Klin, 2013). Understanding *how* face detection processes occur may facilitate our ability to identify whether, when, and how these processes may go awry (Elsabbagh et al., 2013). Although efficient face detection is a well-established phenomenon across the lifespan, the mechanisms that underlie this process remain largely unknown (Buiatti et al., 2019; Lewis & Ellis, 2003). Research on face detection so far has been limited in its almost exclusive focus on human faces, making it unclear whether the attention prioritization effects reported for human faces are generalizable to faces more broadly. That is, do face detection advantages extend to objects that look like faces and animal faces, or are these processing advantages exclusive to own-species (human) faces? This is an important distinction because although human and animal faces may be perceptually similar, animal faces are not as socially relevant, so comparisons of human and animal face processing can help to disentangle perceptual and social contributions to face detection (Yamashiro et al., 2019).

Own-species advantages in face processes have been reported in a variety of domains. For example, in infants, own-species faces are detected and recognized more efficiently than faces of other animals (Heron-Delaney, Wirth, & Pascalis, 2011; Pascalis, de Haan, & Nelson, 2002). These own-species biases appear to be experience driven, emerging during the first year after birth (Damon et al., 2017; Jakobsen, Umstead, & Simpson, 2016; Scott & Fava, 2013). For example, infants as young as 6 months are faster to orient to, and look longer to, human faces compared with animal faces in complex visual displays (Jakobsen et al., 2016). To our knowledge, own-species biases in face detection (i.e., presenting more than two images at a time) have not been tested in infants younger than 6 months, making it unclear when and how these biases emerge. Comparing face detection for human and animal faces can offer insights into the specialization of the face processing system, revealing the extent to which it is broadly tuned or narrowly specialized.

Does inversion disrupt efficient human and animal face detection?

It is unclear what properties underlie face detection advantages and whether these properties are similar across species. Orientation appears to be paramount for efficient face processing. For example, adults are slower to locate inverted faces compared with upright faces (Brown, Huey, & Findlay, 1997; Lewis & Edmonds, 2003, 2005; VanRullen, 2006). Even when faces are task irrelevant—when adults search for a nonface target (e.g., butterfly)—an upright, but not inverted, human face distractor slows performance, suggesting that orientation also influences the automatic attention capture of faces (Langton, Law, Burton, & Schweinberger, 2008). Would inversion similarly influence animal face detection? To our knowledge, this question has not been addressed.

Furthermore, despite these findings in adults, researchers have theorized that infants' attention capture to faces relative to nonfaces is not influenced by face orientation (Elsabbagh et al., 2013). To date, only one study tested this proposal and found that orientation of faces failed to influence

6-month-olds' orienting speed, yet infants fixated more on upright faces compared with inverted faces, suggesting that disrupting facial orientation might not influence attention capture but does influence attention holding (Gliga et al., 2009). However, in that study, each array contained both an upright human face and an inverted human face; when in competition with an upright face, the inverted face may have lost some of its attention prioritization. In addition, other studies in infants report inversion effects in other aspects of face processing such as discriminating facial identity (Turati, Sangrigoli, Ruely, & de Schonen, 2004), facial expressions (Kestenbaum & Nelson, 1990), and race (Hayden, Bhatt, Kangas, Zieber, & Joseph, 2012), so it is possible that infants may display inversion effects in face detection as well.

Does color influence human and animal face detection?

Facial color is another important, yet understudied, source of social information (Thorstenson, Pazda, & Elliot, 2017). Removing color disrupts adults' face detection speed and accuracy (Amso, Haas, & Markant, 2014; Bindemann & Burton, 2009; Lewis & Edmonds, 2005). Faces presented in color are detected more quickly compared to faces presented in grayscale (Lewis & Edmonds, 2005). In addition, coloring faces in unnatural colors further slows detection speed and reduces accuracy, indicating that natural face colors—and not color in general—may enhance detection (Bindemann & Burton, 2009). Would removing color similarly influence animal face detection? Again, it is unclear the extent to which these effects are limited to own-species faces.

Face detection studies in infants primarily use colored images (Elsabbagh et al., 2013; Gliga et al., 2009; Gluckman & Johnson, 2013; Jakobsen et al., 2016; Kwon, Setoodehnia, Baek, Luck, & Oakes, 2016; Mercure et al., 2018). One study used grayscale images and found that 6-month-olds looked longer at human faces (attention holding), but were not more likely to fixate first on human faces (attention capture), compared with objects (Di Giorgio, Leo, Pascalis, & Simion, 2012). However, that study did not include a color control condition, so it is difficult to know whether the latter null result is due to the removal of color. In addition, manipulations to face color influence other aspects of infant face processing, including infants' neural responses to faces (Balas, Westerlund, Hung, & Nelson, 2011). It remains unknown, however, whether infants' face detection may likewise be influenced by manipulations to face color information as well.

Experiment 1

We first explored whether removing color and disrupting upright orientation would alter infants' detection of "faceness" generally (for human and animal faces) or in a more species-specific way. We tested 3- to 5-month-olds because own-species biases in face processing begin to emerge at around this age (Scott & Fava, 2013). For example, 3-month-olds and older infants, compared with newborns, display stronger preferences for human primate eyes compared with nonhuman primate eyes (Dupierrix et al., 2014), faces (Di Giorgio, Méary, Pascalis, & Simion, 2013; Di Giorgio, Turati, Altoè, & Simion, 2012; Sanefuji, Wada, Yamamoto, Mohri, & Taniike, 2014), and bodies (Heron-Delaney et al., 2011). By 6 months of age, infants are more likely to detect, more quickly to detect, and look longer at human animal faces compared with animal faces in complex image arrays (Jakobsen et al., 2016), suggesting that own-species biases are relatively well established by this age. However, the perceptual and social contributions to infant face detection remain largely unexplored (Yamashiro et al., 2019).

We predicted that in infants younger than 6 months, disruptions to low-level features—color and orientation—would slow attention capture, make detection less likely, and reduce looking duration (attention holding) for faces regardless of species. As infants age and their face processing grows more specialized, we predicted that our low-level manipulations would influence their face detection in a more species-specific way and that older infants would show greater species differences compared with younger infants, reflecting the growing social importance of faces. More specifically, we predicted that infants would display an own-species bias—superior attention capture, detection, and attention holding for human faces relative to animal faces—that would be disrupted with the removal

of color and disruptions to upright orientation information, particularly in younger infants, given that infants are newly specialized for their own species (Johnson, Senju, & Tomalski, 2015).

Method

Participants

We recruited families with healthy infants living in or near Harrisonburg, Virginia ($n = 66$) and Miami, Florida ($n = 19$), in the eastern and southeastern United States, respectively, through e-mail, word of mouth, online advertisements, and collaborations with community partners. The final sample consisted of 51 3- to 5-month-olds ($M = 4.3$ months, $SD = 0.9$, range = 2.9–5.6; 28 female; 32 White/Caucasian, 12 Hispanic and White/Caucasian, 3 Black/African American, 3 Hispanic, and 1 Asian, Hispanic, and White/Caucasian) and 34 10- to 11-month-olds ($M = 11.1$ months, $SD = 0.2$, range = 10.5–11.6; 16 female; 29 White/Caucasian, 3 Hispanic, 1 Black/African American, and 1 Hispanic and White/Caucasian). Parents reported their highest level of education, with their responses indicating that 9% completed high school, 8% completed partial college, 41% completed college, 27% completed a master's degree, and 14% completed a doctoral degree. An additional 5 3- to 5-month-olds were tested but excluded due to inattentiveness and/or technical problems. The local ethics committees at James Madison University and the University of Miami approved the study. Parents provided informed consent and received monetary compensation for participating.

Materials

All infants viewed the same stimuli, but in one of three semirandomized orders. Infants viewed up to 27 circular 6-item arrays, 23.5 cm in diameter, subtending a visual angle of 22.2° (see Fig. 1). Photos
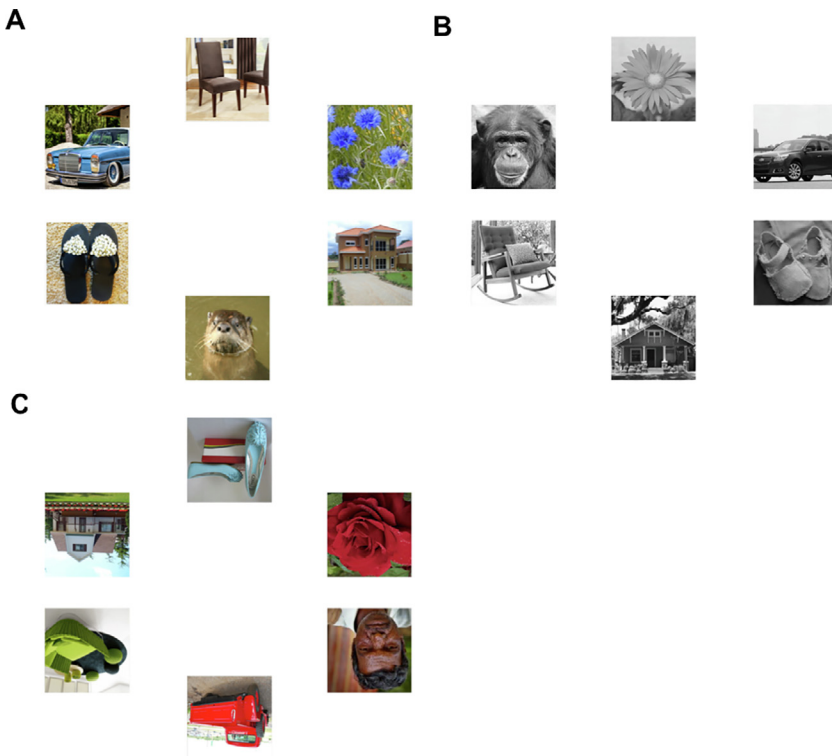
Fig. 1. Sample stimuli in infants' task (Experiment 1): (A) upright color condition; (B) upright grayscale condition; (C) inverted color condition. Each 6-item array contained a face presented among nonface images.

were each sized 6 × 6 cm (visual angle of 5.7° × 5.7°). Arrays were one of three types: upright color, inverted color, or upright grayscale. To keep the task a reasonable length and to ensure that infants observed enough of each type of stimulus, we chose not to include a grayscale inverted condition. Each array contained five unique nonface exemplars—a chair, house, shoe, car, and plant—and a unique neutral face of a human, a chimpanzee, or an otter. We chose these species because we wanted two species to compare with humans, including one more closely evolutionarily related (another primate) and one more distantly related (a nonprimate mammal). We used heterogeneous photos (e.g., diverse backgrounds, lighting, angles; Hershler & Hochstein, 2005) and made identical manipulations to each stimulus (Stein, Sterzer, & Peelen, 2012), systematically varying whether the images were grayscale or in color and whether they were upright or inverted. All photos had visible inner facial features (eyes, nose, and mouth) not obscured by accessories or makeup and had neutral expressions, confirmed by ratings from a separate group of adults (Simpson, Buchin, Werner, Worrell, & Jakobsen, 2014; Simpson, Husband, Yee, Fullerton, & Jakobsen, 2014). Images were obtained through Google Images searches.

We collected gaze data with a Tobii T60 eye tracker (*n* = 26 3- to 5-month-olds and *n* = 23 10- and 11-month-olds) (Tobii Technology, Danderyd, Sweden) and a Tobii TX300 eye tracker (*n* = 27 3- to 5-month-olds and *n* = 11 10- and 11-month-olds) (Tobii Technology, Danderyd, Sweden). We found no statistically significant differences across systems.

Saliency

We used the Saliency Toolbox (www.saliencytoolbox.net) to identify and rank the 12 most salient regions in each array based on color, luminance, and contour (Gluckman & Johnson, 2013; Walther & Koch, 2006). We processed each stimulus array with the Saliency Toolbox, which yielded a salience map and rank ordering of salient regions in the image. For each array, we ranked the most salient regions (a value of 1 = most salient, with larger values indicating less salience). To assess the saliency of the faces, we conducted a one-way analysis of variance (ANOVA) for the target face (human or animal) on these ranked values across each manipulation (upright color, upright grayscale, or inverted color). This revealed no main effect of target face for any of the manipulations (*ps* > .792), indicating that the saliency of human and animal faces likely did not differ.

Procedure

Infants were seated 60 cm from a monitor. Following a 5- or 9-point calibration, infants viewed up to 27 trials in which they were free to look for as long as they liked for up to 8 s. Prior to each trial, attention-getters attracted infants' gaze to the center of the screen. Each array was displayed for 8 s so that infants had enough time to explore some but not all of the images, which we determined with pilot testing and previous studies (Jakobsen et al., 2016). In total, the task lasted approximately 5 min.

Measures

We examined (a) the latencies of infants' first looks to the target faces (i.e., the time from the onset of the array to the time of the first fixation to the target, hereafter referred to as *look speed*), a measure of attention capture (Adler & Gallego, 2014); (b) the proportion of trials in which faces received at least one fixation (*detection*), measured by the likelihood of fixating on a stimulus (Amso et al., 2014), a process reflecting limited attentional resources and selective filtering (Treisman, 1969); and (c) the total fixation time on faces (*attention holding*), a measure of attention maintenance, a reflection of interest, preference, and information extraction (Bronson, 1991; Sasson, Turner-Brown, Holtzclaw, Lam, & Bodfish, 2008). These are related yet independent measures of visual processing that together offer a more complete view of visual processing and face detection than any one measure (Cohen, 1972; Gluckman & Johnson, 2013; Jakobsen et al., 2016).

Data analysis

An a priori power analysis indicated that a sample size of 34 for each infant age group would provide 82% to 89% power for detecting a medium effect size (*f* = .35) for main effects of target species and manipulation and their interaction using *α* = .05 (Cohen, 1988). We extracted gaze data with a Clear-View filter (Tobii Technology) and defined fixations as >100 ms in a 50-pixel radius. Within each array,

a 6 × 6-cm (visual angle of 5.7° × 5.7°) area of interest (AOI) was created around each face for pur-
poses of collecting eye tracking data. The AOI is a region on the screen in which fixations are recorded
by the eye tracker. We examined infants' speed to fixate their gaze on faces (look speed), the propor-
tion of trials with at least one fixation on the face (detection), and the total fixation time on faces
(attention holding). Comparisons were within participants (all infants observed all conditions) for
greater power relative to between-participants designs given that there are considerable individual
differences in infant visual attention (Oakes, 2017). We initially explored the chimpanzee and otter
faces separately, but there were no statistically significant differences; therefore, we pooled infants'
data from these species and referred to them as "animal" faces. All trials with at least one fixation
were included in the analysis. All infants contributed usable data. The 3- to 5-month-olds completed
an average of 16.8 trials (SD = 6.6, range = 5–27), including M = 5.7 (SD = 2.2) human and M = 11.1
(SD = 4.5) animal. More specifically, 3- to 5-month-olds completed M = 1.8 (SD = 0.9) human upright
color, M = 2.3 (SD = 0.8) human inverted color, M = 1.8 (SD = 0.8) human upright grayscale, M = 3.8
(SD = 1.6) animal upright color, M = 3.5 (SD = 1.7) animal inverted color, and M = 3.8 (SD = 1.5) animal
upright grayscale trials. The 10- and 11-month-olds completed an average of 16.6 trials (SD = 5.4,
range = 9–27), including M = 5.4 (SD = 1.8) human and M = 11.2 (SD = 3.7) animal. More specifically,
10- and 11-month-olds completed: M = 1.8 (SD = 0.8) human upright color, M = 2.0 (SD = 0.5) human
inverted color, M = 1.7 (SD = 0.7) human upright grayscale, M = 3.8 (SD = 1.2) animal upright color,
M = 3.6 (SD = 1.5) animal inverted color, and M = 3.8 (SD = 1.2) animal upright grayscale trials.

Results and discussion

Look speed

To measure infants' attention capture, we assessed look speed with a 2 × 3 × 2 mixed-design
ANOVA with within-participants factors of target species (human or animal) and manipulation
(upright color, inverted color, or upright grayscale) and the between-participants factor of age group
(3- to 5-month-olds or 10- and 11-month-olds) (see Fig. 2). We detected a main effect of age group, F
(1, 43) = 48.85, p < .001, η^2 = .53, in which the 10- and 11-month-olds were faster to look to the faces
(M = 1.57 s, SD = 0.50) than the 3- to 5-month-olds (M = 2.82 s, SD = 1.11). There was a main effect of
target species, F(1, 43) = 5.10, p = .029, η^2 = .106, in which infants were faster to look to human faces
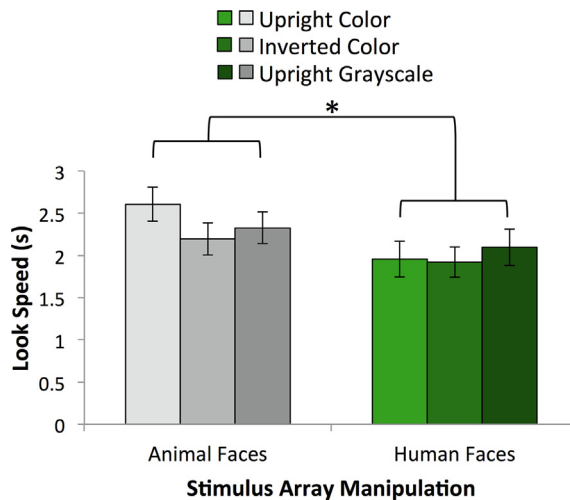
Fig. 2. Infants' look speed to animal faces (gray; left side of figure) and human faces (green; right side of figure) for each
stimulus array manipulation. *p < .05. Error bars reflect standard errors of the means. (For interpretation of the references to
colour in this figure legend, the reader is referred to the web version of this article.)

($M = 2.15$ s, $SD = 1.41$) than to animal faces ($M = 2.43$ s, $SD = 1.29$). There were no other effects ($ps > .05$).

In sum, infants were, overall, faster to look at human faces compared with animal faces. This is consistent with previous reports of own-species bias in 6- and 11-month-olds (Jakobsen et al., 2016) and suggests that own-species bias for face attention capture is surprisingly robust—not entirely disrupted, overall, by low-level manipulations. We also found some age differences. The 3- to 5-month-olds had slower orienting to faces, in general, compared with the 10- and 11-month-olds, consistent with previous studies reporting faster information processing with age across the first year after birth (Rose, Feldman, & Jankowski, 2002).

Detection

To measure infants' face detection, we assessed the proportion of trials with at least one fixation to the face (out of the total number of usable trials) with a $2 \times 3 \times 2$ mixed-design ANOVA with the within-participants factors of target species and manipulation and the between-participants factor of age group (see Fig. 3A). There was a main effect of age group, $F(1, 83) = 42.63$, $p < .001$, $\eta^2 = .34$, in which the 10- and 11-month-olds ($M = .18$, $SD = .06$) were more likely to detect the faces than the 3- to 5-month-olds ($M = .10$, $SD = .05$). There was also a main effect of target species, $F(1, 83) = 13.15$, $p < .001$, $\eta_p^2 = .137$, in which infants were more likely to detect human faces ($M = .14$, $SD = .07$) than animal faces ($M = .12$, $SD = .07$). This main effect was qualified by a Target Species $\times$ Manipulation interaction, $F(2, 166) = 3.27$, $p = .041$, $\eta_p^2 = .038$. To explore this interaction, we first examined the effects of manipulation by holding species constant. One-way repeated-
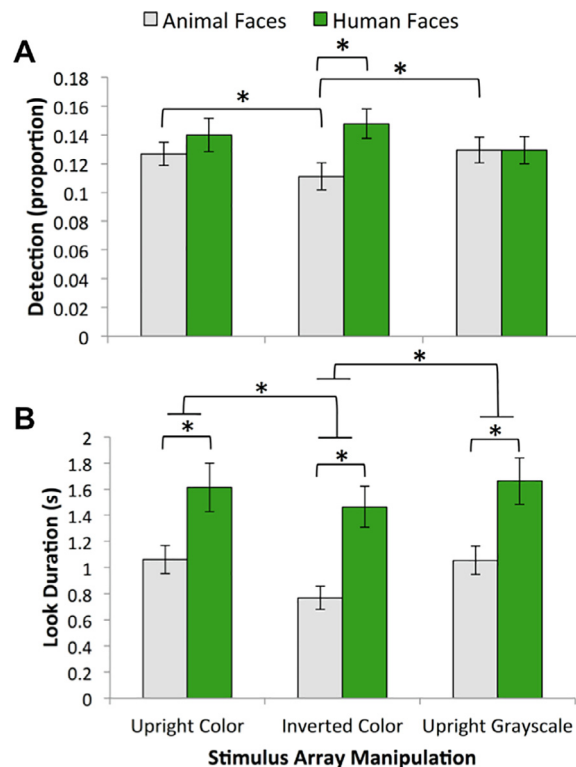
Fig. 3. Infants' detection of (A) and look durations to (B) animal faces (gray; left bars) and human faces (green; right bars) across the stimulus array manipulations. $^*ps < .05$. Error bars reflect standard errors of the means. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

measures ANOVAs for each species revealed no effects of manipulation for the human faces, $F(2, 168)$ = 1.21, p = .302, but an effect of manipulation for the animal faces, $F(2, 168)$ = 3.18, p = .044, η_p^2 = .036, in which the inverted color animal faces (M = .11, SD = .09) were less likely to be detected than either the upright color animal faces (M = .13, SD = .07), $t(84)$ = 2.13, p = .036, d = 0.23, or the upright grayscale animal faces (M = .13, SD = .08), $t(84)$ = 2.21, p = .030, d = 0.24. There were no statistically significant differences between the upright color and upright grayscale conditions, $t(84)$ = 0.33, p = .741. To further explore the significant Target Species × Manipulation interaction, we next held the manipulation type constant and compared species. Paired-samples t tests within each manipulation revealed only a difference in the inverted color condition, in which human faces (M = .15, SD = .09) were more likely to be detected than animal faces (M = .11, SD = .09), $t(84)$ = 4.07, p < .001, d = 0.44. In the upright color and upright grayscale conditions, there were no statistically significant differences in human and animal face detection, $t(84)$ = 1.26, p = .211 and $t(84)$ < .001, p = 1.00, respectively. There were no other significant effects (ps > .05).

Overall, face detection improved in infants between 3–5 and 10–11 months of age, with older infants detecting more faces compared with younger infants, consistent with previous studies (Di Giorgio et al., 2012; Kwon et al., 2016; Leppänen, 2016). We also found that infants were better at detecting human faces than animal faces, consistent with the notion that infants develop an early own-species bias in face detection (Jakobsen et al., 2016). Interestingly, inversion selectively disrupted animal face detection but not human face detection. It appears that different low-level qualities may be playing a role in face detection differently across species.

Look duration

To measure infants' attention holding, we assessed look durations with a 2 × 3 mixed-design ANOVA with the within-participants factors of target species and manipulation and the between-participants factor of age group (see Fig. 3B). There was a main effect of age group, $F(1, 78)$ = 139.94, p < .001, η^2 = .64, in which the 10- and 11-month-olds looked longer (M = 2.02 s, SD = 0.67) than the 3- to 5-month-olds (M = 0.56 s, SD = 0.31). There was also a main effect of target species, $F(1, 78)$ = 37.70, p < .001, η_p^2 = .326, in which infants looked longer to human faces (M = 1.52 s, SD = 1.19) than to animal faces (M = 0.96 s, SD = 0.83). There was also a main effect of manipulation, $F(2, 156)$ = 3.22, p = .042, η_p^2 = .040. Infants looked less to inverted color faces (M = 1.02 s, SD = 0.89) compared with upright color faces (M = 1.20 s, SD = 0.96), $t(84)$ = 2.38, p = .020, d = 0.26, and upright grayscale faces (M = 1.22 s, SD = 1.06), $t(84)$ = 2.28, p = .025, d = 0.25. There were no other significant effects (ps > .05).

Across all low-level manipulations, infants displayed robust own-species bias, looking longer at human faces compared with animal faces. These results are consistent with previous findings of own-species bias in face attention capture and holding in 6- and 11-month-olds (Jakobsen et al., 2016). Already by 3–5 months of age, infants have the capacity to hold their attention longer on socially relevant (own-species) faces even when faces are distorted through inversion or the removal of color. Notably, 3–5 months is the earliest age reported to date of own-species biases in face detection (Dupierrix et al., 2014; Gluckman & Johnson, 2013; Jakobsen et al., 2016; Sanefuji et al., 2014). However, infants were also sensitive to our manipulations, and when faces were inverted for both human and animal faces, infants overall looked less, consistent with a previous study in 6-month-olds (Gliga et al., 2009). This suggests that infants are more likely to engage with upright faces longer than with upside-down faces, and this is not limited to human faces.

Experiment 2

In Experiment 2, we were particularly interested in whether adults' face detection, like that of infants, is influenced by manipulations to face color and orientation in a species-specific way. Studies of face detection in adults have almost exclusively focused on human faces, looking at the influence of orientation (Brown et al., 1997; Langton et al., 2008; Lewis & Edmonds, 2003, 2005; VanRullen, 2006) and color (Amso et al., 2014; Bindemann & Burton, 2009; Lewis & Edmonds, 2005). However, it is unclear whether these qualities influence face processing generally (including faces of humans and

animals) or whether these effects are exclusive to conspecifics (humans). Understanding these own-species biases in adults is necessary to reveal patterns of species-typical development (to understand what ultimately develops), to uncover the malleability of face biases, and to clarify the role of experience in shaping face processing (Scott & Fava, 2013). We predicted that, in adults, disruptions to color and orientation would slow detection and recognition for faces generally but that own-species bias would still be evident even with these alterations. We predicted that these low-level disruptions would slow face detection and recognition for animal faces more than for human faces.

Method

Participants

Adults (n = 120) participated for course credit at James Madison University (M_{age} = 18.7 years, SD = 1.0; 94 female; 97 White/Caucasian, 7 Black/African American, 8 Asian, 5 Hispanic, 1 Egyptian, 1 African American/Hispanic/White, and 1 unknown), and all reported normal or corrected-to-normal vision. Adults were randomly assigned to one of four stimulus conditions—upright color, inverted color, upright grayscale, or inverted grayscale—until each condition had 30 participants. We chose a between-participants design because we did not want participants to see each array more than once and we wanted to avoid fatigue effects. The stimuli of interest were embedded within a longer task with smaller (16- and 32-item) visual search arrays not analyzed in the current study. The local ethics committee at James Madison University approved the study. We obtained informed consent from all participants.

Materials

Adults viewed 18 arrays, each containing 64 colored photographs in an 8 × 8 grid (see Fig. 4). There were 6 arrays for each of three target face types (human, chimpanzee, and otter). These stimuli were the same as those used in a previous study (see Experiment 2 in Simpson, Buchin, et al., 2014) except they were manipulated to make four conditions: upright color, in which the original arrays were shown; inverted color, in which the arrays were flipped vertically so that all items were upside-down; upright grayscale, in which color was removed; and inverted grayscale, in which the arrays were both flipped vertically and color was removed. Photographs were sized 2.5 × 2.5 cm (visual angle of 2.4° × 2.4°). We chose faces using the same criteria as in Experiment 1. Target locations within the arrays were balanced across conditions and species. We used faces as distractors in the adult task to make the task more challenging; the more similar the targets and distractors, the more difficult it is to distinguish them (Simpson, Husband, et al., 2014). Photos were collected through Google Images searches.

We recorded eye movements via corneal reflection using a Tobii T60 eye tracker, with a 43-cm monitor positioned 60 cm from participants and a sampling rate of 60 Hz. We used Tobii Studio software (Tobii Technology, Danderyd, Sweden) to collect and summarize data. Participants completed a 5-point eye gaze calibration before testing.

Saliency

We conducted saliency analyses as in Experiment 1. We detected no main effect of target for any of the manipulations (ps > .472), indicating that the human and animal faces did not appear to differ in their saliency.

Procedure

In each trial, participants viewed an array and were instructed to search for a particular type of face (i.e., "Find the human/chimpanzee/otter faces") and to indicate the targets' locations (left side, right side, or not present) with a key press. The key press ended the trial. Participants completed three test blocks, one for each species (6 human, 6 chimpanzee, and 6 otter), for a total of 18 trials (18 arrays). Each block contained only one type of target (faces of humans, chimpanzees, or otters) and one type of distractor (faces of humans, chimpanzees, or otters). Block order was counterbalanced across participants. Participants were randomly assigned to one of four conditions: color upright, color inverted, grayscale upright, or grayscale inverted. We focus only on the eye-tracking data because they are more

Fig. 4. Sample stimuli in adults' visual search task (Experiment 2): (A) upright color condition; (B) upright grayscale condition; (C) inverted color condition; (D) inverted grayscale condition. Each 64-item array contained a target (a human face in these examples). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

sensitive than manual responses (Pereira, Birmingham, & Ristic, 2019; Simpson, Buchin, et al., 2014; Simpson, Husband, et al., 2014).

Measures

We measured the latencies of first looks to the target faces (i.e., the time from the onset of the array to the time of the first fixation to the target (*look speed*). Look speed is a measure of attention capture (Adler & Gallego, 2014; Adler & Oprecio, 2006; Franklin, Pilling, & Davies, 2005). We measured total fixation time on target faces (i.e., the time between the first fixation to the target and the time the trial ended when the key was pressed (*decision speed*), reflecting how long it took adults to identify the item as the target face, a measure of recognition efficiency (Vachon & Tremblay, 2012; Vu, Tu, & Duerrschmid, 2016). We measured *face detection* (i.e., the proportion of trials with at least one fixation to the target face out of the total number of trials), reflecting the likelihood of fixating on a face. These measures were different from those we used with infants (in Experiment 1) because our goal was to devise age-appropriate tasks to enable the most sensitive measures of face detection within each age group.

Data analysis

An a priori power analysis indicated that a sample size of 30 for each between-participants group would provide 77–85% power for detecting a medium effect size (f = .35) for main effects of target species and manipulation and their interaction using α = .05 (Cohen, 1988). We extracted gaze data in the same way as in Experiment 1. Within each array, equally sized AOIs were created around targets (2.5 × 2.5 cm; visual angle of 2.4° × 2.4°). There were no statistically significant effects for face detection, so we excluded that measure. We explored the chimpanzee and otter faces separately, but there were no statistically significant differences, so we combined these categories and referred to them as "animal" faces. We analyzed data with and without outliers (<2% of trials that fell >2.5 standard deviations from the mean), and results were the same, so we retained all trials.

Results and discussion

Look speed

We assessed look speed with a 2 × 2 × 2 mixed-design ANOVA exploring the within-participants factor of target (human or animal) and the between-participants factors of orientation (upright or inverted) and color (color or grayscale). This revealed a main effect of target, F(1, 116) = 26.54, p < .001, η_p^2 = .186, in which looks to human faces (M = 3.21 s, SD = 2.03) were faster than looks to animal faces (M = 4.39 s, SD = 2.41) (see Fig. 5A). There were also main effects of color, F(1, 116) = 7.16, p = .009, η^2 = .058, and orientation, F(1, 116) = 22.99, p < .001, η^2 = .165. Looks were faster to faces presented in color (M = 3.61 s, SD = 1.78) compared with grayscale (M = 4.45 s, SD = 2.01), and looks were faster to upright faces (M = 3.33 s, SD = 1.22) compared with inverted faces (M = 4.72 s, SD = 2.26). There were no interactions (ps > .05).

In sum, own-species attention capture was evident across all manipulations. That is, adults were faster to look at human faces compared with animal faces regardless of orientation or color, suggesting robust own-species bias in face attention capture, consistent with previous reports (Simpson, Buchin, et al., 2014; Simpson, Husband, et al., 2014). However, with either color removed or when inverted, adults' attention capture was slowed for both human and animal faces. There may be additive effects of these individual components (i.e., species, orientation, and color), suggesting broadly tuned detection mechanisms that may be activated by faces generally and not specifically responsible for human face detection. This finding is in contrast to our findings in infants that indicated a more species-specific pattern of attention capture, with infants' own-species bias being disrupted by inversion. However, it is also possible that our failure to detect an interaction between species and our manipulations in adults may indicate that this task was insensitive for detecting such differences and, like any null result, should be interpreted with caution.

Decision speed

We assessed decision speed with a 2 × 2 × 2 mixed-design ANOVA exploring target, orientation, and color. This revealed a main effect of target, F(1, 116) = 4.35, p = .040, η_p^2 = .036, in which adults were slower with animal faces (M = 0.52 s, SD = 0.24) than with human faces (M = 0.47 s, SD = 0.25), a main effect of orientation, F(1, 116) = 12.92, p < .001, η^2 = .100, in which adults were faster for upright faces (M = 0.43 s, SD = 0.15) compared with inverted faces (M = 0.56 s, SD = 0.25), and a main effect of color that approached statistical significance, F(1, 116) = 3.58, p = .061, η^2 = .030, in which adults were faster for faces in color (M = 0.46 s, SD = 0.17) compared with grayscale (M = 0.53 s, SD = 0.24) (see Fig. 5B). There were no interactions (ps > .05), suggesting that human and animal faces were similarly influenced by color and orientation manipulations.

It took adults longer to identify animal face targets compared with human face targets regardless of the low-level manipulation. This parallels the attention capture finding, suggesting robust own-species face processing. Similar to the attention capture finding, distorting stimuli—either by removing color or through inversion—slowed decision speed. Together, these results suggest that both processes have notable own-species biases that occur in spite of changes to low-level qualities. Furthermore, these measures offer converging evidence that whereas infants' face detection was influenced by inversion in a species-specific way, adults' face detection was not. Whereas infants, who have less mature face detection capacities, may initially rely more on low-level image qualities,
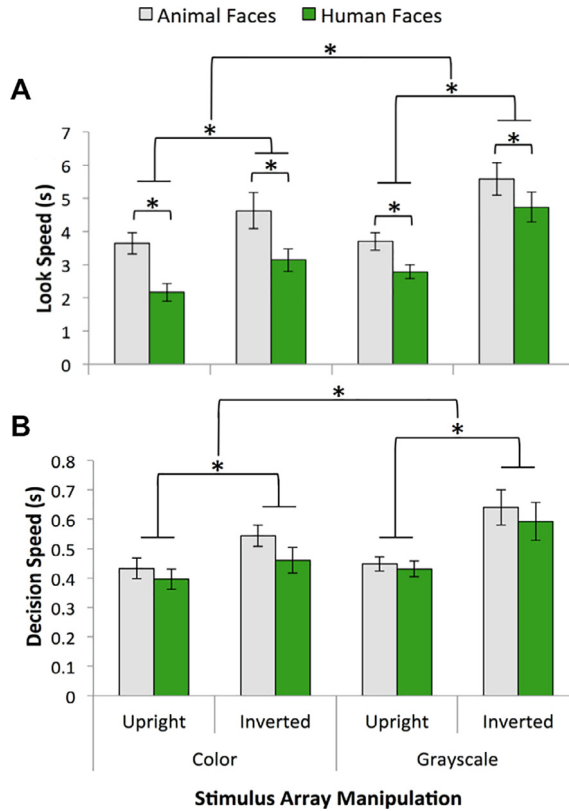
Fig. 5. Adults' look speed (A) and decision speed (B) for animal faces (gray; left bars) and human faces (green; right bars) across the stimulus array manipulations. *ps < .05. Error bars reflect standard errors of the means. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

adults' face detection may instead be driven by higher-level categorical information (Hershler & Hochstein, 2005, 2006).

General discussion

For infants, like adults, faces appear to be a special class of stimuli, eliciting more rapid detection and efficient processing relative to other object categories (Di Giorgio et al., 2012; Elsabbagh et al., 2013; Frank et al., 2014; Gliga et al., 2009; Gluckman & Johnson, 2013; Jakobsen et al., 2016; Kwon et al., 2016). In the current study, we began to address these gaps by systematically manipulating two features—orientation (upright vs. inverted) and color (natural skin/hair colors vs. grayscale)—to determine whether their disruptions influence 3- to 11-month-old infants' and adults' face detection. We found that infants, like adults, were *faster* and *more likely* to detect human faces compared with animal faces and looked *longer* to human faces than to animal faces, own-species biases that strengthened with age. We also found that manipulations to color and orientation disrupted some aspects of face detection in infants and adults; however, these qualities differently affected face detection across attentional measures, species, and age. Most surprising, infants' face detection was influenced by low-level manipulations in a species-specific way—reducing their animal face detection but largely unaffecting their human face detection—whereas adults' face detection was equally affected in a broader species-general way.

Orientation influences on infant face detection and attention holding

Interestingly, for infants, there may be distinct features in human and animal faces that attract their attention. In contrast to adults, both 3- to 5-month-olds' and 10- and 11-month-olds' face detection efficiencies were disrupted by low-level manipulations in a species-specific way. For instance, in both infant groups, inversion selectively disrupted animal face detection but not human face detection. Different low-level features may underlie human and animal face detection in infants, with upright orientation playing a more critical role in animal face detection. Infants are often lying down while awake, so they see human faces in a wide variety of orientations (Sugden & Moulson, 2017). Therefore, it is possible that inversion may be more disruptive for animal face detection because, relative to human faces, infants have less experience with animal faces, especially in inverted orientations.

Orientation also affected infants' attention holding in a species-general fashion; infants looked longer to upright faces compared with inverted faces for both human and animal faces. This finding suggests that infants were more interested in exploring upright faces, consistent with previous reports of greater attention holding for upright human faces compared with inverted human faces in 6-month-olds (Gliga et al., 2009). The current study extends these findings, showing that inversion similarly influences attention holding of animal faces as well, and reveals that these patterns emerge even earlier—by 3–5 months of age.

Species-general orientation and color influences on adult face detection

Adults' attention capture and decision speed—the rapidity with which adults identified targets once they looked at them—were slowed by the disruption of color and orientation in a non-species-specific way. These findings build on previous studies reporting that disruptions to orientation and color reduce human face detection speed and accuracy (Amso et al., 2014; Bindemann & Burton, 2009; Brown et al., 1997; Langton et al., 2008; Lewis & Edmonds, 2003, 2005; VanRullen, 2006), revealing for the first time that these effects are not limited to human faces but also extend to animal faces, suggesting that these qualities affect face detection more broadly. Adults might not use these low-level features in unique ways for human faces, at least not in the context of an active visual search task. Furthermore, our results replicate and extend previous findings of own-species bias in face detection (Hershler & Hochstein, 2005; Simpson, Buchin, et al., 2014; Simpson, Husband, et al., 2014), demonstrating that these biases are extraordinarily robust in spite of disruptions to orientation and color.

These findings bring up an intriguing question: Are there species-general effects of orientation and color, or might there be species-specific effects that we simply could not detect in the current study? Although speculative, one interpretation of our pattern of results—failing to find species-specific effects of our low-level manipulations in adults—is that they may be due to the diversity of our human face stimuli. Adults are more sensitive to face manipulations, such as inversion effects, when faces are more familiar, including face race and age (Colombatto & McCarthy, 2017; Macchi Cassia, 2011), and our faces varied widely in these dimensions. Consequently, this diversity may have put our adults at a disadvantage, making the task more challenging. This facial diversity could also potentially explain why our infants showed species-specific inversion effects but adults did not. Infants develop own-race bias—improvements in processing the types of faces that they see most often—across the first months after birth (for a review, see Lee, Quinn, & Pascalis, 2017) and, therefore, during early infancy are processing human faces more as "generalists" than adults, sensitive to a wider range of faces (Sugden & Marquis, 2017). In sum, assuming that experience likely drives face specialization processes (Balas & Saville, 2017; Sunday, Dodd, Tomarken, & Gauthier, 2019), it seems reasonable that adults, compared with infants, likely have more mature and specific face detection, particularly for faces that are upright and in color, whereas infants have broader, less well specified face detection abilities. Further studies that systematically vary these factors are necessary to explore which of these interpretations, if any, are correct.

Future directions

Our goal was not to directly compare infants and adults but rather to explore the patterns within each age group. Because adults and infants participated in different tasks to ensure that the tasks were

developmentally appropriate, direct comparisons across age groups were not possible. The methodological differences between infant and adult tests may account for our apparent age differences; however, we think that it is unlikely. Previous studies manipulated these methodological factors in adults and found own-species bias in attention capture and holding consistently regardless of the specific task (Simpson, Buchin, et al., 2014; Simpson, Husband, et al., 2014). Furthermore, despite these methodological differences, we found a similar pattern of results for both infants and adults—efficient own-species face detection relative to animal face detection even with disruption to orientation and color. Future work will be necessary to test whether faces in other contexts—such as when they are task irrelevant—differently automatically capture adults' attention as a function of low-level manipulations. There are, of course, a number of other dimensions that were not explored here, but that are equally intriguing, such as race, emotional expression, and eye contact. Furthermore, there may be other low-level features, such as luminance, texture, and shape, or particularly salient features, such as the eyes (Gliga & Csibra, 2007), that underlie this own-species bias.

Conclusions

Infants display an early attraction to social stimuli (Shultz, Klin, & Jones, 2018). Faces are one of the most socially and biologically relevant categories (Palermo & Rhodes, 2007; Yamashiro et al., 2019). Attention to faces appears to be an early marker of social sensitivity, offering a window into the development of socially adaptive preferences (Peltola et al., 2018; van Rijn, Urbanus, & Swaab, 2019). The current study revealed robust specialized processing of own-species faces earlier during infancy than previously reported, uncovering new ways in which own-species faces are unique.

Acknowledgments

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2019.05.001.

References

Adler, S. A., & Gallego, P. (2014). Search asymmetry and eye movements in infants and adults. *Attention, Perception, & Psychophysics, 76*, 1590–1608.
Adler, S. A., & Oprecio, J. (2006). The eyes have it: Visual pop-out in infants and adults. *Developmental Science, 9*, 189–206.
Amso, D., Haas, S., & Markant, J. (2014). An eye tracking investigation of developmental change in bottom-up attention orienting to faces in cluttered natural scenes. *PLoS One, 9*(1) e85701.
Balas, B., & Saville, A. (2017). Hometown size affects the processing of naturalistic face variability. *Vision Research, 141*, 228–236.
Balas, B., Westerlund, A., Hung, K., & Nelson, C. A. III, (2011). Shape, color and the other-race effect in the infant brain. *Developmental Science, 14*, 892–900.
Bindemann, M., & Burton, A. M. (2009). The role of color in human face detection. *Cognitive Science, 33*, 1144–1156.
Bradshaw, J., Klin, A., Evans, L., Klaiman, C., Saulnier, C., & McCracken, C. (2009). Development of attention from birth to 5 months in infants at risk for autism spectrum disorder. *Development and Psychopathology*.. https://doi.org/10.1017/S0954579419000233.
Bronson, G. W. (1991). Infant differences in rate of visual encoding. *Child Development, 62*, 44–54.
Brown, V., Huey, D., & Findlay, J. M. (1997). Face detection in peripheral vision: Do faces pop out? *Perception, 26*, 1555–1570.
Buiatti, M., Di Giorgio, E., Piazza, M., Polloni, C., Menna, G., Taddei, F., ... Vallortigara, G. (2019). Cortical route for facelike pattern processing in human newborns. *Proceedings of the National Academy of Sciences of the United States of America, 116*, 4625–4630.
Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum.

Cohen, L. B. (1972). Attention-getting and attention-holding processes of infant visual preferences. *Child Development, 43*, 869–879.

Colombatto, C., & McCarthy, G. (2017). The effects of face inversion and face race on the P100 ERP. *Journal of Cognitive Neuroscience, 29*, 664–676.

Damon, F., Méary, D., Quinn, P. C., Lee, K., Simpson, E. A., Paukner, A., ... Pascalis, O. (2017). Perception of facial averageness: Evidence for a common mechanism in human and macaque infants. *Scientific Reports, 7*, 46303.

Di Giorgio, E., Leo, I., Pascalis, O., & Simion, F. (2012). Is the face-perception system human-specific at birth? *Developmental Psychology, 48*, 1083–1090.

Di Giorgio, E., Méary, D., Pascalis, O., & Simion, F. (2013). The face perception system becomes species-specific at 3 months: An eye-tracking study. *International Journal of Behavioral Development, 37*, 95–99.

Di Giorgio, E., Turati, C., Altoè, G., & Simion, F. (2012). Face detection in complex visual displays: An eye-tracking study with 3- and 6-month-old infants and adults. *Journal of Experimental Child Psychology, 113*, 66–77.

Dupierrix, E., de Boisferon, A. H., Méary, D., Lee, K., Quinn, P. C., Di Giorgio, E., ... Pascalis, O. (2014). Preference for human eyes in human infants. *Journal of Experimental Child Psychology, 123*, 138–146.

Elsabbagh, M., Gliga, T., Pickles, A., Hudry, K., Charman, T., Johnson, M. H., & BASIS Team (2013). The development of face orienting mechanisms in infants at-risk for autism. *Behavioural Brain Research, 251*, 147–154.

Frank, M. C., Amso, D., & Johnson, S. P. (2014). Visual search and attention to faces during early infancy. *Journal of Experimental Child Psychology, 118*, 13–26.

Franklin, A., Pilling, M., & Davies, I. (2005). The nature of infant color categorization: Evidence from eye movements on a target detection task. *Journal of Experimental Child Psychology, 91*, 227–248.

Gliga, T., & Csibra, G. (2007). Seeing the face through the eyes: A developmental perspective on face expertise. *Progress in Brain Research, 164*, 323–339.

Gliga, T., Elsabbagh, M., Andravizou, A., & Johnson, M. (2009). Faces attract infants' attention in complex displays. *Infancy, 14*, 550–562.

Gluckman, M., & Johnson, S. P. (2013). Attentional capture by social stimuli in young infants. *Frontiers in Psychology, 4*. https://doi.org/10.3389/fpsyg.2013.00527.

Hayden, A., Bhatt, R. S., Kangas, A., Zieber, N., & Joseph, J. E. (2012). Race-based perceptual asymmetry in face processing is evident early in life. *Infancy, 17*, 578–590.

Heron-Delaney, M., Wirth, S., & Pascalis, O. (2011). Infants' knowledge of their own species. *Philosophical Transactions of the Royal Society of London B: Biological Sciences, 366*, 1753–1763.

Hershler, O., & Hochstein, S. (2005). At first sight: A high-level pop out effect for faces. *Vision Research, 45*, 1707–1724.

Hershler, O., & Hochstein, S. (2006). With a careful look: Still no low-level confound to face pop out. *Vision Research, 46*, 3028–3035.

Jakobsen, K. V., Umstead, L., & Simpson, E. A. (2016). Efficient human face detection in infancy. *Developmental Psychobiology, 58*, 129–136.

Johnson, M. H., Senju, A., & Tomalski, P. (2015). The two-process theory of face processing: Modifications based on two decades of data from infants and adults. *Neuroscience & Biobehavioral Reviews, 50*, 169–179.

Jones, W., & Klin, A. (2013). Attention to eyes is present but in decline in 2–6-month-old infants later diagnosed with autism. *Nature, 504*, 427–431.

Kelly, D. J., Duarte, S., Meary, D., Bindemann, M., & Pascalis, O. (2019). Infants rapidly detect human faces in complex naturalistic visual scenes. *Developmental Science*. https://doi.org/10.1111/desc.12829.

Kestenbaum, R., & Nelson, C. A. (1990). The recognition and categorization of upright and inverted emotional expressions by 7-month-old infants. *Infant Behavior and Development, 13*, 497–511.

Kwon, M. K., Setoodehnia, M., Baek, J., Luck, S. J., & Oakes, L. M. (2016). The development of visual search in infancy: Attention to faces versus salience. *Developmental Psychology, 52*, 537–555.

Langton, S. R., Law, A. S., Burton, A. M., & Schweinberger, S. R. (2008). Attention capture by faces. *Cognition, 107*, 330–342.

Lee, K., Quinn, P. C., & Pascalis, O. (2017). Face race processing and racial bias in early development: A perceptual–social linkage. *Current Directions in Psychological Science, 26*, 256–262.

Leppänen, J. M. (2016). Using eye tracking to understand infants' attentional bias for faces. *Child Development Perspectives, 10*, 161–165.

Lewis, M. B., & Edmonds, A. J. (2003). Face detection: Mapping human performance. *Perception, 32*, 903–920.

Lewis, M. B., & Edmonds, A. J. (2005). Searching for faces in scrambled scenes. *Visual Cognition, 12*, 1309–1336.

Lewis, M. B., & Ellis, H. D. (2003). How we detect a face: A survey of psychological evidence. *International Journal of Imaging Systems and Technology, 13*(1), 3–7.

Macchi Cassia, V. (2011). Age biases in face processing: The effects of experience across development. *British Journal of Psychology, 102*, 816–829.

Mayer, K. M., Vuong, Q. C., & Thornton, I. M. (2015). Do people "pop out"? *PLoS One, 10*(10) e139618.

Mercure, E., Quiroz, I., Goldberg, L., Bowden-Howl, H., Coulson, K., Gliga, T., ... MacSweeney, M. (2018). Impact of language experience on attention to faces in infancy: Evidence from unimodal and bimodal bilingual infants. *Frontiers in Psychology, 9*. https://doi.org/10.3389/fpsyg.2018.01943.

Oakes, L. M. (2017). Sample size, statistical power, and false conclusions in infant looking-time research. *Infancy, 22*, 436–469.

Palermo, R., & Rhodes, G. (2007). Are you always on my mind? A review of how face perception and attention interact. *Neuropsychologia, 45*, 75–92.

Pascalis, O., de Haan, M., & Nelson, C. A. (2002). Is face processing species-specific during the first year of life? *Science, 296*, 1321–1323.

Peltola, M. J., Yrttiaho, S., & Leppänen, J. M. (2018). Infants' attention bias to faces as an early marker of social development. *Developmental Science, 21* e12687.

Pereira, E. J., Birmingham, E., & Ristic, J. (2019). The eyes do not have it after all? Attention is not automatically biased towards faces and eyes. *Psychological Research*. https://doi.org/10.1007/s00426-018-1130-4.

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2002). Processing speed in the 1st year of life: A longitudinal study of preterm and full-term infants. *Developmental Psychology, 38*, 895–902.

Sanefuji, W., Wada, K., Yamamoto, T., Mohri, I., & Taniike, M. (2014). Development of preference for conspecific faces in human infants. *Developmental Psychology, 50*, 979–985.

Sasson, N. J., Turner-Brown, L. M., Holtzclaw, T. N., Lam, K. S., & Bodfish, J. W. (2008). Children with autism demonstrate circumscribed attention during passive viewing of complex social and nonsocial picture arrays. *Autism Research, 1*, 31–42.

Scott, L. S., & Fava, E. (2013). The own-species face bias: A review of developmental and comparative data. *Visual Cognition, 21*, 1–28.

Shultz, S., Klin, A., & Jones, W. (2018). Neonatal transitions in social behavior and their implications for autism. *Trends in Cognitive Sciences, 22*, 452–469.

Simion, F., & Di Giorgio, E. (2015). Face perception and processing in early infancy: Inborn predispositions and developmental changes. *Frontiers in Psychology, 6*. https://doi.org/10.3389/fpsyg.2015.00969.

Simpson, E. A., Buchin, Z., Werner, K., Worrell, R., & Jakobsen, K. V. (2014). Finding faces among faces: Human faces are located more quickly and accurately than other primate and mammal faces. *Attention, Perception, & Psychophysics, 76*, 2175–2183.

Simpson, E. A., Husband, H. L., Yee, K., Fullerton, A., & Jakobsen, K. V. (2014). Visual search efficiency is greater for human faces compared to animal faces. *Experimental Psychology, 61*, 439–456.

Stein, T., Sterzer, P., & Peelen, M. V. (2012). Privileged detection of conspecifics: Evidence from inversion effects during continuous flash suppression. *Cognition, 125*, 64–79.

Sugden, N. A., & Marquis, A. R. (2017). Meta-analytic review of the development of face discrimination in infancy: Face race, face gender, infant age, and methodology moderate face discrimination. *Psychological Bulletin, 143*, 1201–1244.

Sugden, N. A., & Moulson, M. C. (2017). Hey baby, what's "up"? One- and 3-month-olds experience faces primarily upright but non-upright faces offer the best views. *Quarterly Journal of Experimental Psychology, 70*, 959–969.

Sunday, M. A., Dodd, M. D., Tomarken, A. J., & Gauthier, I. (2019). How faces (and cars) may become special. *Vision Research*. https://doi.org/10.1016/j.visres.2017.12.007.

Thorstenson, C. A., Pazda, A. D., & Elliot, A. J. (2017). Subjective perception of color differences is greater for faces than non-faces. *Social Cognition, 35*, 299–312.

Treisman, A. M. (1969). Strategies and models of selective attention. *Psychological Review, 76*, 282–299.

Turati, C., Sangrigoli, S., Ruely, J., & de Schonen, S. (2004). Evidence of the face inversion effect in 4-month-old infants. *Infancy, 6*, 275–297.

Vachon, F., & Tremblay, S. (2012). What eye tracking can reveal about dynamic decision-making. In K. Stanney & K. S. Hale (Eds.), *Advances in cognitive engineering and neuroergonomics* (pp. 157–165). Boca Raton, FL: CRC Press.

van Rijn, S., Urbanus, E., & Swaab, H. (2019). Eyetracking measures of social attention in young children: How gaze patterns translate to real-life social behaviors. *Social Development*. https://doi.org/10.1111/sode.12350.

VanRullen, R. (2006). On second glance: Still no high-level pop-out effect for faces. *Vision Research, 46*, 3017–3027.

Vu, T. M. H., Tu, V. P., & Duerrschmid, K. (2016). Design factors influence consumers' gazing behaviour and decision time in an eye-tracking test: A study on food images. *Food Quality and Preference, 47*, 130–138.

Walther, D., & Koch, C. (2006). Modeling attention to salient proto-objects. *Neural Networks, 19*, 1395–1407.

Yamashiro, A., Sorcinelli, A., Rahman, T., Elbogen, R., Curtin, S., & Vouloumanos, A. (2019). Shifting preferences for primate faces in neurotypical infants and infants later diagnosed with ASD. *Autism Research, 12*, 249–262.