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The development of visual search in infancy: Attention to faces versus salience

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Abstract

Four experiments examined how faces compete with physically salient stimuli for the control of attention in 4-month-old, 6-month-old, and 8-month-old infants (N = 117 total). Three computational models were used to quantify physical salience. We presented infants with visual search arrays containing a face and familiar object(s), such as shoes and flowers. Six- and 8-month-old infants looked first and longest at faces; their looking was not strongly influenced by physical salience. In contrast, 4-month-old infants showed a visual preference for the face only when the arrays contained 2 items and the competitor was relatively low in salience. When the arrays contained many items or the only competitor was relatively high in salience, 4-month-old infants' looks were more often directed at the most salient item. Thus, over ages of 4 to 8 months, physical salience has a decreasing influence and faces have an increasing influence on where and how long infants look.

Keywords

attention; face; salience; development; infancy

The ability to select and attend to specific objects in cluttered visual scenes is critically important for effective learning about the information in those scenes. Consider the images depicted in Figure 1, taken from Amso, Haas, and Markant's (2014) study of developmental changes in attention. The images on the left illustrate the overwhelming complexity of our everyday environment—each scene contains many different shapes and colors, with more objects that can be processed all at once. For effective learning, infants need to selectively attend to important objects and ignore objects or features that are irrelevant at a given moment, even if those irrelevant objects or features are physically salient.

This selection process is determined by the level and type of competition between the items in scenes. Some items and features generate strong "attend-to-me" signals (Sawaki & Luck, 2010) that can pull infants' attention toward those items and features. Similarly, once

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fixated, aspects of the items and features will determine how long infants maintain fixation before shifting their gaze to a different region of the scene. Moreover, different features contribute to these *attention-getting* and *attention-holding* aspects of visual attention. In a classic study, Cohen (1972) observed that attention-holding, or how long infants looked at a stimulus, was related to the complexity of a stimulus (i.e., the number of checks in a checkerboard). Attention-getting, or how quickly infants looked at the stimulus, was related to salience (i.e., the size of the checks). Attention develops over the course of infancy (Colombo, 2001), resulting in changes in the features that effectively capture and maintain infants' attention. Specifically, young infants are *stimulus driven* or have *obligatory* attention (Stechler & Latz, 1966); they appear to be compelled to attend to some stimulus features over others (e.g., red rather than green objects, Dannemiller, 1998, 2000) and are unable to control attention voluntarily (Johnson, 2010). Across the first year, infants' attentional control becomes more sophisticated, sometimes described as becoming more endogenously or voluntarily controlled, because they use high-level processes such as goals or knowledge to determine where to look (Ruff & Rothbart, 1996). As a result, the impact of some features on attention-getting and attention-holding will vary across development.

In the present investigation, we asked how physically salient items and human faces compete for young infants' attention-getting and attention-holding processes when presented in arrays containing multiple items. Each array contained a face as a "target." Several previous studies have shown preferences for faces in multiple item arrays (Di Giorgio, Turati, Altoe, & Simion, 2012; Gliga, Elsabbagh, & Andravizou, 2009; Gluckman & Johnson, 2013). Faces may attract attention for many reasons—because they are relevant for some unspecified goal, because they are familiar, or because previous experience has generated a relatively automatic face attention response. Because such factors—goal-related processes, familiarity, and experience— should have increasing influence on attention over infancy, faces are a convenient stimulus for assessing the effect of such factors on infants' attention. Here, we use "social relevance" to describe faces (in contrast with "physical salience" defined by low-level features), but we are agnostic as to whether infants' attention to faces is driven by some understanding of the social nature of those stimuli.

The images on the right side of Figure 1 illustrate how physical salience and social relevance can be decoupled. Sometimes, regions of high salience correspond with relevant or meaningful objects; for example, according to a computational model of stimulus salience (Walther & Koch, 2006) the face in scene A is highly salient (Amso et al., 2014). Other times, they differ; for example, the face in B is not very salient. Here we ask how different types of stimuli—faces and physically salient items—compete for and control attention in infants between 4 and 8 months of age. This is also an issue of considerable interest in adults' visual attention. Although physical salience contributes to where adults look (Donk & van Zoest, 2008; Siebold, van Zoest, & Donk, 2011), goals and meaning have a strong influence on adult eye movements, particularly when viewing natural, complex scenes (Henderson, Brockmole, & Castelhano, 2007; Moores, Laiti, & Chelazzi, 2003). Moreover, top-down processes can influence the direction (or target of) and latency of adults' first saccades or fixations (Hollingworth, Matsukura, & Luck, 2013a; 2013b; Leonard & Luck, 2011). Faces, in particular, seem to be frequent targets of adult eye movements—adults look more at faces than at other objects when freely viewing scenes (Cerf, Frady, & Koch, 2009); they can make fast and accurate saccades toward face stimuli (Fletcher-Watson, Findlay, Leekam, & Benson, 2008); and their tendency to fixate social aspects of scenes (e.g., eyes of human faces) appears to be unrelated to the physical saliency of those regions (Birmingham, Bischof, & Kingstone, 2009).

Given evidence that attentional control develops between 4 and 6 months, shifting from being highly influenced by stimulus factors to being more influenced by top-down control (Johnson, 2010), we predicted developmental changes in the way competition between physical salience and social relevance (as defined here) influences infants' attention. Specifically, we expect a shift in the relative influence of physical salience and social relevance over development, with a bias toward social relevance in older infants. Importantly, our predictions are not about developing face processing or understanding of social relevance. Rather, our predictions are about how infants' developing attentional control reflects their ability to balance competing factors—low-level physical salience and higher-level stimulus features.

We predict that, over the course of infant development, faces will be increasingly effective at holding attention. We base this prediction on previously reported findings. Frank, Vul, and Johnson (2009) reported increases from 3 to 9 months in interest in (i.e., looking at) faces during free-viewing of video clips from *A Charlie Brown Christmas*, a finding that was replicated and extended to movies involving real people in Frank, Amso, and Johnson (2014). Di Giorgio, Turati, Altoè, and Simion (2012) found that 6-month-old infants, but not 3-month-old infants, looked longer than expected by chance at faces presented in static arrays of 4 or 6 complex objects. During free viewing of the scenes in Figure 1, Amso et al. (2014) observed that looking time to faces increased between 4 and 24 months, although this was not the main focus of their study.

Young infants have shown different patterns of preference for faces across experiments. For example, although some studies have shown that young infants fail to prefer faces (e.g., Di Giorgio et al., 2012), even newborn infants *can* show preferences for face-like stimuli when presented with two items side-by-side (e.g., Farroni et al., 2005). One potential reason for discrepant results is that in previous studies features of the distractor object(s) varied considerably across studies. It is, therefore, difficult to draw conclusions about why infants might show a face preference in some contexts but fail to show such a preference in other contexts. We predict that as infants' attentional control develops, they become better able to direct their looking toward more meaningful, relevant, or familiar stimuli, and this will be reflected in their emerging preference for faces. A corollary of this prediction is that younger infants will be drawn toward more salient features rather than faces, at least under some circumstances. Indeed, Frank et al. (2009, 2014) observed that younger (i.e., 3-month-old) infants' looking was more driven by physical salience in a particular region than by the presence of a face in that region. Moreover, Frank et al. (2014) showed that infants' developing face preference was related to their performance on visual search, suggesting a strong connection between developing attentional control and face preference.

We also predict that, over the course of infant development, faces will become more effective at *getting* infants' attention—that is, older infants will direct more of their initial looks at faces than will younger infants. This prediction may seem counterintuitive, given that bottom-up processes are thought to play an important role in eye movement control (Henderson, 2003). However, the target of the first look or saccade in adults is a function of the competition between bottom-up and top-down processes, and under some conditions adults' first looks are more consistent with their goals or tasks than with low-level physical salience (Hollingworth et al., 2013a). We therefore predict that infants' attention-getting reflects their developing ability to control attention in the context of competition between low-level and high-level stimulus features, and as a result, older infants will be more likely to direct their first looks at the faces in the visual arrays. Previous studies have shown that infants look first at faces and other socially relevant stimuli in some arrays of items (Gliga, et al., 2009; Gluckman & Johnson, 2013). This effect is fragile, however. DeNicola, Holt, Lambert, and Cashon (2013), for example, observed that although 4- to 8-month-old infants looked *longer* at a face that was paired with a colorful novel toy, they did not look *first* at the face. Similarly, Di Giorgio et al. (2012) found that although both 6-month-old infants and adults looked longest at a face presented in an array of 6 complex items, only adults looked at the faces first more than expected by chance. Thus, even when faces significantly influence attention-holding, they may not have as strong an effect on infants' attention-getting.

There are three issues with these previous studies that limit the conclusions we can draw, however. First, the investigations did not include a systematic evaluation of the features of the non-face distractors, making it impossible to know how physical salience impacts infants' first looks (e.g. DeNicola et al., 2013; Di Giorgio et al., 2012). Second, because the number of items per array differed across studies (e.g. 2 items in DeNicola et al.'s study versus 6 items in Di Giorgio et al., 2012), the discrepant findings may reflect differences in overall attentional demand.

We examined attention-getting and attention-holding of face and non-face stimuli of varying salience within multiple-object arrays in 4-, 6-, and 8-month-old infants. We expected that 6- and 8-month-old infants would attend strongly to the face and that their attention-getting and attention-holding would be only minimally influenced by physical salience. In contrast, we expected that attention-getting and attention-holding by 4-month-old infants would be more influenced by the physical salience of the items, and that the direction of their eye movements and duration of their fixations would be determined by the combination of physical salience and social relevance. To further investigate how this competition is different under higher and lower processing demands, we also manipulated the number of items in the visual arrays between Experiments 1 and 2. Because of the increasing emphasis on replicability in the life sciences (Pashler, & Wagenmakers, 2012), we also conducted an experiment to assess the replicability of the central results from Experiment 1.

General Method

Participants

All infants included in the final samples were full-term, healthy, and not at risk for colorblindness based on family history. Infants were drawn from a diverse population, and the demographics of our final sample reflect this diversity. We included 117 infants, either 4, 6, or 8 months of age, in the four samples reported here; each infant was included in only one experiment. Seventy-six infants were Caucasian, 6 were Asian, 1 was African American, 26 were mixed race, and race was not reported for 8 infants. Across these groups, 32 of the infants were reported to be Hispanic. One hundred and thirteen mothers had graduated from high school and 73 out of the mothers had earned at least a Bachelor's degree. An additional 57 infants were tested but excluded from the final analyses (see Table 1 for detailed information about exclusion).

We obtained infant names from the State Office of Vital Records. Parents were sent informational mailings with instructions on how to volunteer and be included in our database of potential research participants. When infants reached the appropriate age for this study, we contacted parents about participating. Infants received a certificate and a small toy or t-shirt for participating.

Apparatus

Infants' eye movements were recorded by an Applied Science Laboratory (ASL) pan/tilt eye-tracker; model R6 in Experiments 1 and 2A, and model D6 in Experiment 2B. Both the R6 and D6 systems capture eye gaze at a rate of 60Hz, and are pan/tilt, monocular systems. Regardless of the system used, the same algorithm was used to determine eye gaze. The ASL eye camera was located below a 37-inch Westinghouse LCD monitor on which the stimuli were presented. The eye camera was focused on the infant's right eye, and the ASL system determined the direction of gaze by detecting pupil and corneal reflection from an infrared light source. To account for head movements, the ASL system used a magnetic head-tracking system (*Ascension Mini Bird*), which communicated the position of the head in multi-dimensional space to the eye tracker. This allowed a servo motor to adjust the camera position to keep the eye in view. We used one Dell computer to control the ASL eye-tracker and a second Dell to present stimuli on the Westinghouse monitor, using custom programs created in Adobe Director 11.

Stimuli

The primary stimuli were digitized color photographs of 6 categories of objects-human faces, flowers, sippy cups, shoes, vehicles, and teddy bears (see Figure 2). Images were edited so they were approximately equivalent in size; in the main experiment reported in Experiment 1, the items were approximately 7.1° wide × 4.0° high at a viewing distance of 100 cm, and in the replication of Experiment 1 and Experiments 2A and 2B, the items were 5.1° wide × 4.0° high at a viewing distance of 100 cm. The mean luminance value of the items was 77.0 cd/m^2, and the luminance values for each individual item fell within 2 standard deviations (14.0) from this mean.

We selected 12 different exemplars for each of the 6 categories; within each category, the 12 items varied in color, shape, and other details. The face images were obtained from the NimStim Face Stimulus Set (Tottenham, Tanaka, Leon, McCarry, Nurse, Hare, et al., 2009) with permission from the authors. We selected 6 male and 6 female faces, all shown in front view and smiling, varying in race (Caucasian, African American, or Asian). The flower images were of a single flower (no stem), and varied in color, shape, etc. (e.g., lily, sunflower, rose). The sippy cups were presented in frontal view and varied in color, material, and detail (e.g., metal, plastic). The teddy bears were presented in frontal view, were seated, and varied in color and other features (e.g., long fur, short fur, curled fur). The vehicles were presented in profile and varied in make, model, and color. The shoes were children's shoes depicted in ¾ view, and varied in color, detail, and decoration.

These stimuli were used in all experiments and were presented in arrays of 6 (Experiments 1A and 1B) or 2 (Experiments 2A and 2B) on a uniform grey background (63.0 cd/m^2). In Experiment 1, each trial involved an array including one item from each category, arranged in either an ellipse (main experiment, 1A) or a circle (replication, 1B) around the center fixation. In Experiment 1A, each item was located 7.9° or 8.5° from the center of the ellipse (see Figure 2), and in Experiment 1B each item was located 7.9° from the center of the circle. In Experiment 2, each trial involved an array including two items: a face and a flower (Experiment 2A) or a face and a shoe (Experiment 2B). The items were presented at 2 of the locations used in Experiment 1B, positioned 180° across the circle.

Salience

In each experiment, our first step was to evaluate the relative salience of the items in the stimulus arrays shown to infants. Each individual stimulus array that was shown to the infants was run through several MATLAB toolboxes that provide information about the most salient objects/regions in scenes. There is significant debate about which computational model predicts human eye gazes most accurately (Judd, Durand, & Torralba, 2012), and verification of salience models with adult viewers have yielded somewhat different outcomes depending on the nature of the task (Koehler, Guo, Zhang, & Eckstein, 2014). Moreover, it is not known which toolbox best reflects infant vision. Therefore, we assessed the salience using three toolboxes, and our analyses were based on the convergence of at least two of the three toolboxes (the analyses when determining salience with individual toolboxes are presented in Appendix A). This sort of complexity is, at present, an unavoidable consequence of studying infant attention with complex, real-world stimuli such as faces in the absence of well validated models of saliency computations in infant vision.

We used the Saliency (IK) toolbox (Walther & Koch, 2006) because it has been used recently in other studies of face perception involving infants and young children (e.g., Amso et al., 2014; Amso, Haas, Tenenbaum, Markant, & Sheinkopf, 2013; Gluckman & Johnson, 2013). We used the GBVS toolbox because it has been shown to better predict adult eye gaze (Harel, Koch, & Perona, 2007; Judd, Durand, & Torralba, 2012). We used the AIM model (Bruce & Tsotsos, 2009) because it has been known to better predict adults' looking behavior for a free-viewing task than the IK model (as instantiated in the Saliency toolbox). None of these toolboxes were designed to reflect infant vision; however, because they mainly focus on factors such as contrast and feature discontinuities and do not require high spatial resolution or complex features, they should provide a reasonable estimate of physical salience in infant vision. Moreover, if they successfully predict gaze patterns in the present experiments, this will demonstrate that they provide a good approximation of salience in infants. Finally, given that they are based on adult vision, it is reasonable to assume that they will provide a better approximation in older infants than in younger infants. However, if we see that they predict looking *more accurately* in younger infants than in older infants, this cannot be explained by a poorer ability of the models to estimate salience in younger infants.

In addition, we used the Saliency (IK) toolbox (Walther & Koch, 2006) to extract three individual feature maps—color, intensity, and orientation—for each array to determine the relative salience and which features contribute to the overall salience of each category of item (see Appendix B for details). These analyses, detailed in Appendix B, indicate that color and intensity, but not orientation, were the main determinants of differences in salience between the items in our stimulus arrays.

Procedure

All experiments reported here used the same basic procedure. Infants sat on their parent's lap, in front of and approximately 100 cm from the LCD monitor and 75 cm from the ASL eye-tracker. Parents wore occluding (felt-covered) sunglasses to minimize bias (i.e., they could not see the arrays during the experimental procedure).

Each session began with a standard procedure to calibrate the infants' point-of-gaze to the eye-tracker, adapted from that used by Oakes, Baumgartner, Barrett, Messenger, and Luck (2013) and Oakes and Ellis (2013). A looming circle is presented in locations on the video monitor, and an experimenter indicates when the infant looks at each circle; the corneal and pupil reflections when infants are looking at those known locations are used by the eye tracking system to determine point of gaze (POG) during the experimental trials. We presented the looming circle in 5 locations (center of the screen, and four corners of a virtual square, 9.1° to the left or right of the center and 6.9° above or below the center). Immediately after the calibration procedure, we conducted a visual verification of the quality of the calibration (e.g., checking whether the POG, as indicated by cross-hairs superimposed on the stimulus, fell on looming dots presented at locations on the screen). If the quality was not good, calibration was repeated. In addition, we conducted a visual verification of calibration again after the sixth experimental trial by presenting each infant with 2 to 3 looming circles. We conducted an additional check of the accuracy of the offline-coding on this mid-experiment verification by having coders view the video recording for all infants who participated in our experiments and determine whether infants' fixations of the calibration points fell on the region covered by the looming circle or near that stimulus (in a region 25% bigger than (i.e. 0.5° extended around) the calibration point at its largest). Of the 282 locations verified, 95% fell on the looming circles and 5% fell in the extended circle. Thus our calibration procedure yielded POG data sufficiently accurate to determine whether and how quickly infants fixated the 6 locations in our arrays.

Immediately after calibration, all infants received 12 experimental trials. First, a fixation cross repeatedly flashed at the center of the monitor, and once the infant fixated the cross (as indicated by the POG superimposed on it) the experimenter initiated an experimental trial. For each trial, the computer program randomly selected the particular instance of each item category and presented them in the 6- or 2-item arrays, depending on the experiment. Across the 12 trials, each infant saw all 12 instances of each category, and each item was presented twice in each of the 6 possible locations during the experimental session. To help maintain infants' attention, classical music accompanied the visual array on each trial.

Data processing and reduction

We defined 7 areas of interest (AOIs), one for each of the 6 item locations and a seventh corresponding to the location of the fixation cross (Figure 3). Each AOI extended approximately 0.1° beyond each edge of the corresponding image. To minimize noise in the data, we used an online smoothing filter, which replaced each recorded sample with the average of the current sample and the previous 3 samples. We also used a blink filter; loss of pupil for 12 or fewer samples was considered a blink, and the missing data were interpolated if the location of the gaze did not change from before to after the blink.

We adopted the following inclusion criteria, based on practices adopted in previous studies (e.g., Di Giorgio et al., 2012; Gliga et al., 2009). First, we included only trials in which infants looked at the fixation cross for at least 100 ms at the start of the trial; this ensured that we included in our analyses only trials in which infants were stably fixating on the center of the display when the 6 images appeared. Second, we included only trials in which infants looked for at least 200 ms total at the 6 object AOIs combined over the entire course of the trial (Oakes et al., 2013; Oakes & Ellis, 2013); this ensured that we included only trials that contained meaningful data. Finally, we included in our analyses only infants who contributed at least 6 trials that met these two criteria.

We processed the data in several steps. First, we used the *ASLresults* program to generate for each trial a list of the x and y coordinates of the gaze at each sample and identify the first fixation. We used the following fixation definition: a gaze maintained within a 1° region for at least 100 ms. Next, we used custom MATLAB software to process the data and calculate both the total duration of time (i.e., the number of samples) infants spent looking at each of the 7 AOIs on each trial and the target of infants' first fixation (as just defined) outside of the central AOI on each trial.

In addition to examining infants' sustained *fixation* within specified AOIs, which is commonly assessed in infancy, we assessed infants' *saccades* (an eye movement that lands in a given AOI, whether or not this is followed by a sustained fixation), which is typically used in adult studies. These two measures are obviously correlated, but are not necessarily identical. Due to developmental changes in infants' eye movements, it is possible that infants' first saccades do not end in a sustained fixation (e.g., ≥ 100 ms) within a specified dispersion region (e.g., Adler & Orprecio, 2006). To determine whether the two measures provide significantly different insight into the attention-getting process, we report both measures here. We used the ILAB MATLAB toolbox (Gitelman, 2002) to identify the first saccade within each trial. ILAB determined the onset of a saccade using a minimum eye velocity threshold of 30°/s (Fischer, Biscaldi, & Otto, 1993). Once the saccades were identified, we used Adler and Orprecio's (2006) guidelines for determining the direction of the first saccade. That is, we included eye movements that 1) began at least 133 ms after the onset of the visual array, 2) originated within the central AOI before the onset of the visual array, and 3) traced a path that was more than 50% of the distance between the fixation cross and the center of any of the object AOIs. As a result of applying these conservative criteria to our data, we included 54% to 77% of the trials in the analyses for each experiment (this is comparable to the percentage of trials included by Adler and Orprecio, which was 65% to 76%).

Experiment 1

Our first experiment examined developmental changes between 4 and 8 months in infants' eye movements in response to arrays of 6 items. Specifically, we expected a strong influence of faces on older, but not younger, infants' attention-getting and attention-holding—i.e., they would look first and longest at the human face. We expected that younger infants' attention would be more influenced by physical salience; specifically, we predicted that they would look first at the most salient item and that attention-holding would be more influenced by physical salience in these infants than in older infants.

Experiment 1A

Method—The final sample included 22 4-month-old infants (10 boys and 12 girls; *M* = 124 days, *SD* = 7.15), 15 6-month-old infants (10 boys and 5 girls; *M* = 188 days, *SD* = 5.90), and 16 8-month-old infants (8 boys and 8 girls; *M* = 250 days, *SD* = 6.32).

Each trial was 5 s in duration and contained a stimulus array consisting of 6 complex objects arranged in a circle around fixation, as shown in Figure 3. Table 2 provides the results of our stimulus salience analyses, and includes the proportion of trials in which the item from each of the 6 categories was determined to be the most salient item within an array. Our main analyses on saliency were limited to the trials in which at least two toolboxes identified the same item as being the most salient (analyses based on each individual toolbox are presented in Appendix A). It is clear from Table 2 that the *flower* category was determined to be the most salient item on the highest proportion of trials and that faces were almost never the most salient item in a given array.

It is important to note that that saliency is not a property of a single object but instead reflects the context in which the object is presented (i.e., the other objects and their spatial locations). For example, the purple flower might be the most salient item when presented to one infant within an array of yellowish items, but it might not be the most salient item when presented to another infant within an array containing several other purple items. Thus, saliency was estimated for each stimulus array. In addition, the saliency toolboxes do not provide absolute quantitative estimates of the degree of saliency of the most salient item. Rather, they are designed to determine the relative salience of the items within a given array. Thus, our analyses focus on which object was the most salient within a given array, and Table 2 shows the likelihood that an object from a given category was the most salient item across all arrays used in the experiment.

Results—We conducted separate analyses of *attention-getting* and *attention-holding*, as defined earlier.

Attention-getting: Our first set of analyses evaluated attention-getting by the face and by the most physically salient item in a given array. For reasons described earlier, we separately analyzed the target of infants' first *fixation* and the direction of their first *saccade*. On average, each infant contributed 10.51 trials (SD = 1.44) to the fixation analyses and 9.13 trials (SD = 1.70) to the saccade analyses.

We calculated the proportion of trials for which first fixations or first saccades were directed toward the face and the proportion of first fixations and first saccades directed toward the most salient item (*regardless of category*) in each array (that is, the flower if the flower was most salient, the sippy cup if it was most salient, and so on). Because there are 6 items in these arrays, random looking would lead to 1/6 (or .167) of first fixations or first saccades being directed to any one item. Although 6- and 8-month-old infants were highly likely to look first to the face, 4-month-old infants were not. Instead, 4-month-old infants' first fixations tended to be directed to the most salient item in the array (Figure 4).

Our first analyses compared to chance (.167) the proportion of first fixations and first saccades that infants directed to *faces*. These comparisons confirmed that 4-month-old infants' first fixations, $t(21) = 1.22$, $p = .236$, $d = .26$, and their first saccades, $t(21) = -.62$, $p = .540$, $d = .13$, were not directed toward the face more than expected by chance. Six- and 8-month-old infants, in contrast, did direct both their first fixations and first saccades to faces more than expected by chance: significant effects were found for the proportion of 6-month-old infants' first fixations directed to faces, $t(14) = 5.63$, $p < .001$, $d = 1.46$; the proportion of 6-month-old infants' first saccades directed to faces, $t(14) = 5.41$, $p < .001$, $d = 1.40$; the proportion of 8-month-old infants' first fixations directed to faces, $t(15) = 6.80$, $p < .001$, $d = 1.70$; and the proportion of 8-month-old infants' first saccades directed to faces, $t(15) = 6.28$, $p < .001$, $d = 1.57$. In sum, although 6- and 8-month-old infants' first eye movements were directed toward the faces in these arrays, the faces were not the target of 4-month-old infants' first eye movements.

In addition, we analyzed the latencies of these first fixations relative to the onset of the stimulus array (see Table 3). We compared infants' latencies for first looks to faces to their first looks to all other categories of items. As is seen in Table 3, these latencies did not differ by age or by category. Indeed, an ANOVA conducted on these latencies with age (4-, 6-, and 8-months) as the between-subjects factor and stimulus type (face versus non-face) as the within-subjects factor did not reveal any main effects or interactions, ps >.1. In summary, although older infants directed more first looks toward faces than toward non-faces, they were not faster to do so.

Next, we conducted the same analyses for infants' first fixation and first saccade toward the most salient item in each array. Because we only included trials in which two or more toolboxes indicated that the same item was the most salient, fewer trials were available for analysis. The analyses of first fixations included on average 6.8 trials (SD = 1.8) at 4 months, 7.1 trials (SD = 2.0) at 6 months, and 7.3 trials (SD = 1.3) at 8 months, and the analyses of first saccades included on average 5.4 trials (*SD* = 2.0) at 4 months, 6.4 trials (*SD* = 1.7) at 6 months, and 5.8 trials (*SD* = 1.6) at 8 months. We excluded from our analyses 2 four-month-old infants who had only 1 trial in which two or more toolboxes converged on the same item as the most salient item, although analyses including those two infants did not differ dramatically from the results reported here.

The 4-month-old infants were more likely than expected by chance to direct their first fixations to the most salient item, $t(19) = 2.21$, $p = .04$, $d = .49$. Six- and 8-month-old infants did not direct their first fixations to the most salient item more than expected by chance (in 6-month-old infants, $t(14) = .21$, $p = .84$, $d = .05$; in 8-month-old infants, $t(15) = -.77$, $p = .45$, $d = .19$). Unlike the first fixations, first saccades were not directed toward the most salient item more than expected by chance at any age (for 4-month-olds, $t(19) = 1.61$, $p = .12$, $d = .36$; for 6-month-olds, $t(14) = 1.04$, $p = .32$, $d = .27$; and for 8-month-olds, $t(15) = -.35$, $p = .73$, $d = .09$).

Together, these one-sample t-tests suggest a developmental difference: 4-month-old infants direct their first fixation toward physically salient items more than expected by chance, and 6- and 8-month-old infants direct their first fixation toward faces more than expected by chance. We directly tested this developmental pattern by entering the mean proportion of first fixations and the mean proportion of first saccades to faces into separate Analyses of Variance (ANOVAs) with Age (4-, 6-, and 8-months) as the between-subjects factor. Both analyses revealed significant main effects of age for proportion of first fixations directed at faces, $F(2, 50) = 18.70$, $p < .001$, $\eta^2_p = .428$, and the proportion of first saccades directed at faces, $F(2, 50) = 23.95$, $p < .001$, $\eta^2_p = .489$. Scheffé post-hoc comparisons of the proportion of fixations directed at faces revealed that performance was significantly lower in 4-month-old infants than in 6- and 8-month-old infants, both *p*s < .001, but the 6- and 8-month-old infants did not differ from each other, $p = .445$. Similarly, Scheffé post-hoc comparisons indicated that the proportion of first saccades directed at faces was significantly lower in 4-month-old infants than in 6- and 8-month-old infants, both *p*s < .001, but the 6- and 8-month-old infants did not differ from each other, $p = .216$. Thus, these analyses confirm that the face was less effective at eliciting a first look from 4-month-old infants than from 6- and 8-month-old infants.

The corresponding ANOVAs conducted on the proportion of first fixations directed toward the most salient item as determined by at least two toolboxes also showed this developmental difference, $F(2, 48) = 3.32$, $p = .044$, $\eta^2_p = .122$. Scheffé post-hoc comparisons revealed that 4-month-old infants had a marginally higher proportion of fixations to the most salient item than did 8-month-old infants, $p = .064$. Infants' latencies for their first look to the most salient item versus any of the other items, however, did not reveal any significant main effects or interactions, *ps* >.318 (see Table 3), suggesting no age differences in the speed of eye movements.

Because the flower was the most salient item most of the time, it is possible that this effect of salience actually reflects infants' preferences for *flowers*. We examined this by reanalyzing the proportion of infants' first fixation on the trials used for the salience analyses. When considering the *flower* as the target, 4-month-old infants did not make more first fixations to the flower than expected by chance, p = .216, d = .29. Indeed, in this subset of trials only infants' first fixations to *shoes* differed from chance, and they actually had fewer first fixations to shoes than expected by chance, $t(19) = -2.22$, p = .039, d = .50, consistent with our analyses indicating that the shoes, like the faces, were the least salient items (see Appendices A and B).

Taken together, these analyses indicate that different stimulus properties controlled attention-getting for younger and older infants. In the displays used in the present study, in which faces were not physically salient, 4-month-old infants did not direct their initial looking at the faces. Instead, they often looked at the most salient item in the array, consistent with stronger influence of exogenous factors over attention-getting at this age. In contrast, older infants were able to overcome physical salience and were more likely to direct their initial looking at the faces, indicating more sophisticated control over attention.

Attention-holding: Next, we examined the relative duration of infants' looking to each of the 6 targets to determine how effective the face and/or the most salient item was at *holding* infants' attention. To equate for differences in overall interest across age and trials, we calculated the proportion of time infants spent looking at the face or the most salient item score by dividing the duration of looking to the target AOI (the face for one set of analyses and the most salient item for the other set) by the total amount of looking to all 6 AOIs for each trial. Thus, as with the attention-getting measure, chance was .167.

The mean proportion of looking at the face and at the most salient item is presented in Figure 5. The difference between our attention-holding and attention-getting measures is striking: whereas the initial fixation was directed at the face above chance only in the 6- and 8-month-old infants, infants of all 3 ages spent more overall time looking at the face than expected by chance. However, consistent with the finding that only 4-month-old infants directed their initial looks to the most salient item, only the 4-month-old infants showed above-chance looking time for the most salient item.

We confirmed this impression of the relative effectiveness of the face and most salient item to hold infants' attention by conducting the same analyses described for the first fixations and first saccades. All three age groups looked at faces more than expected by chance (4-month-olds, $t(21) = 4.01$, $p < .005$, d = 0.86, 6-month-olds, $t(14) = 6.37$, $p < .001$, d = 1.64, and 8-month-olds, $t(15) = 8.48$, $p < .001$, d = 2.12). However, comparisons to chance of the proportions of total amount of time infants spent looking at the most salient item in each array failed to reveal a strong preference for the most salient item in 6-month-old, $t(14) =$ 6.37, p = .72, d = .09, and 8 month-old infants, $t(15) = -1.71$, p = .11, d = .43. Only 4-month-old infants looked longer than chance at the most salient item, $t(19) = 2.26$, p = .04, d= .50.

Next, we assessed the statistical significance of age differences in attention-holding. An ANOVA on the proportion of looking to the face revealed a main effect of age, F (2, 50) = 18.70, $p < .001$, $\eta^2_p = .428$. Scheffé post-hoc comparisons revealed that the proportion of total looking toward the face by 6- and 8-month-old infants was significantly greater than the proportion of the total looking toward the face by 4-month-old infants, ps < .001; the proportions of looking times of 6- and 8-month-old infants did not differ significantly, p = .445. Thus, although infants in all three age groups exhibited significant attention-holding by the faces, this effect was stronger in the older infants.

The ANOVA on the proportion of infants' looking to the most salient item also revealed a significant main effect of age, F (2, 48) = 3.80, p = .029, η^2_p = .137, confirming that attention-holding by physically salient objects also differed across age groups. Scheffé post-hoc comparisons revealed that the proportion of total looking toward the most salient item by 8-month-old infants was significantly lower than the proportion of the total looking toward the most salient item by 4-month-old infants, p = .033. Once again we examined the proportion of infants' looking to the flowers in these trials and found that 4-month-old infants did not look at the flower longer than expected by chance, p = .294, d= .241. This result indicates that infants' looking to the most salience item is more than their attention to the category of flowers.

In summary, Experiment 1 revealed a developmental change in which the influence of physical salience on infants' looking reduced over age, with the social relevance of the stimulus having a stronger influence in older infants' looking. Although younger infants showed a preference for faces (i.e., they looked at faces more than expected by chance), their preference for faces was reduced compared to older infants, and unlike older infants they did not direct their first eye movements toward faces more than expected by chance, instead showing more of their initial looking than expected by chance at the most salient item in the array.

Experiment 1B

Method—Given that our 4-month-old infants showed a different pattern of results than did our older infants, and that this pattern differs from how older infants have responded in previously published studies, we ran a replication of this experiment with a new sample of 4-month-old infants (10 boys and 10 girls; M = 125 days, SD = 7.34). The design, apparatus, stimuli, and procedure were identical to those in the main experiment except for two slight modifications. First, our trial lengths in Experiment 1B were 12 s (in contrast to the 5 s trials in Experiment 1A). Increasing our trial lengths would confirm that the results of Experiment 1A were not a function of presenting young infants with an insufficient opportunity to learn about and visually explore the stimuli. Second, we altered the array somewhat, so each item was the same distance (7.9° at a viewing distance of 100 cm) from the center; this manipulation necessitated decreasing the size of images to 5.1° wide × 4.0° high. In this way, none of the items was closer to fixation than any of the other items, removing a potential source of uncontrolled variance. On average, 10.25 trials (SD = 1.37) contained valid fixation data and 9.10 trials (SD = 1.45) met our criteria for saccades.

The analyses of salience using the three saliency toolboxes yielded results that were consistent with those from Experiment 1A (see Table 2): faces were rarely rated as the most salient item in the array; the flower was most frequently determined to be the most salient item for all three toolboxes; the flower was judged as the most salient by a convergence of the toolboxes on nearly half of the trials; and the face was never judged as the most salient item by a convergence of the toolboxes (see Appendices A and B).

Results—The proportion of infants' first fixations and first saccades to the face or most salient item are presented in Figure 4, and the results replicated the pattern observed in Experiment 1A. The proportions of first fixations and first saccades to faces were not significantly higher than expected by chance ($t(19) = -.34$, $p = .734$, $d = .08$ for fixations; $t(19) = -.31$, $p = .758$, $d = .07$ for saccades). In contrast, the proportion of first fixations and saccades directed to the most salient item were both greater than expected by chance ($t(19) = 3.21$, $p = .005$, $d = .72$ for fixations; $t(19) = 2.35$, $p = .03$, $d = .53$ for saccades). Once again, examining the proportion of first fixations to *flowers* for these trials revealed that infants did not look more at flowers than expected by chance, $t(19) = 1.74$, $p = .099$, $d = .39$ The latencies for infants' first fixations categorized by stimulus type and relative salience are given in Table 3 (note that because our trials in Experiment 1B were longer than the trials in Experiment 1A, comparison of the latencies by 4-month-old infants in the two experiments is difficult). Once again, we observed that 4-month-old infants had similar latencies to faces and non-faces and they had similar latencies to the most salient and all other items (see Table 3); neither of these comparisons revealed a significant difference. Thus, as in Experiment 1A, although 4-month-old infants had a higher proportion of first fixations to the most salient item, their latencies to look at that item were not faster than their latencies when they first looked at a different item.

An analysis of the proportion of time spent looking at the face or the most salient item in each array also corroborated the results of Experiment 1A. Infants devoted more looking than expected to chance to the faces, $t(19) = 2.98$, $p = .008$, $d = .67$, and the proportion of looking directed toward the most salient item was modestly—but not significantly—greater than chance, $t(19) = 1.81$, $p = .09$, $d = .41$ (see Figure 5). As in Experiment 1A, infants did not look more at flowers than expected by chance, $t(19) = 0.17$, $p = .986$, $d = .004$. These results confirm that 4-month-old infants' initial looking is substantially driven by physical salience, whereas social significance can influence attention-holding.

Discussion

The results of these two experiments show developmental changes in the characteristics of stimuli that contribute to *attention-getting* and *attention-holding* between 4 and 6 months of age, at least for visual arrays containing multiple unique, complex, and potentially familiar items. By 6 months, both attention-getting and attention-holding are more strongly influenced by faces than by physical salience, whereas 4-month-old infants are more strongly drawn by salience, especially in terms of attention-getting. However, although faces did not produce significant attention-getting in 4-month-old infants, both faces and physically salient objects influenced attention-holding in these infants.

In general, these results fit with what we know about the development of attention and the processes that influence attention-getting and attention-holding in infancy. The initial classic studies on attention-getting and attention-holding suggested that different features contribute to each process (Cohen, 1972). Specifically, at 4 months, the *complexity* of the stimulus was related to how long infants looked (attention-holding), but the *salience* (i.e., size in Cohen's study) contributed to how quickly infants' looked toward the object (attention-getting). Our results show an analogous pattern: higher-order properties of the stimulus (e.g., social relevance) contributed to attention-holding whereas *physical salience* was the only significant contributor to attention-getting in our younger infants. Moreover, unlike the classic studies of Cohen (1972), in which physical salience was determined based on the experimenter's intuition (i.e., bigger items in a pattern = more salient stimulus), here we adopted a systematic computational approach to evaluating salience. Inspection of Figure 4 shows that infants' responding was influenced by both social relevance and physical salience, but to different degrees across ages. Although older infants' response to the faces was significantly greater than chance and younger infants' response to the most salient item was significantly greater than chance, both groups were influenced to some extent by both types of features.

We observed the same general pattern reported by Di Giorgio et al. (2012), Gluckman and Johnson (2013), and Gliga et al. (2009), using somewhat different procedures. Together, these studies indicate that older infants are more attentive to faces than are younger infants, and faces contribute more to attention-holding than attention-getting in this context. However, our results go beyond these previous studies and also provide insight into the features that *do* control young infants' looking in this context. Specifically, we showed that 4-month-old infants were not simply looking at random; they were actually selectively attending to the most salient item in the array. This observation is consistent with the general view—and existing evidence—that infants' visual attention is mainly stimulus-driven before 6 months of age (Johnson, 2010). That is, likely due to maturational changes in the neural structures that underlie the visual system, infants' visual attention becomes increasingly controlled by *endogenous*, higher-order factors, and less controlled by *exogenous*, low-level sensory factors. Frank et al. (2009) drew similar conclusions based on findings that although faces held 9-month-old infants' attention longer than did non-face objects, visually salient objects held 3-month-old infants' attention longer than did faces.

Other studies have examined the role of physical salience on infants' attention to faces in stimulus arrays. For example, Gluckman and Johnson (2013) used the IK toolbox to evaluate the relative salience of the faces in their visual search arrays. They found that infants' interest in the faces embedded in their arrays did not vary as a function of the salience of those faces—the 6-month-old infants in that study selectively attended to faces regardless of whether or not those faces were highly physically salient. This is similar to our finding that 6-month-old infants attended to the faces in our arrays despite the fact those faces were rarely the most physically salient item in the array. Similarly, Amso et al. (2014) observed that infants' looking at faces in naturalistic scenes was not a function of how salient those faces were in those scenes. Thus, these previous studies examined infants' attention to more or less salient *faces*. We examined for the first time the competing influences of physical salience and social relevance, assessing infants' attention to faces that were not highly salient versus highly salient non-face objects.

Experiment 2

The results of Experiment 1 are consistent with the conclusion that 4-month-old infants' attention allocation is initially strongly driven by exogenous or stimulus factors, although attention holding is influenced by both salience and social relevance. However, it is possible that this balance depends on other features of the context. In Experiment 1, we specifically asked how infants directed their attention to arrays of 6 items presented on relatively short trials, a context that mimics many of the demands on infants' visual attention in their everyday interactions with the world. However, the brief duration and large number of items produce a challenging context in which to direct attention. In Experiment 2 we made the context less challenging by presenting only two items in each display, thus reducing the attentional demands. We may observe that under these conditions young infants can more easily balance the conflicting demands of physical salience and social relevance in controlling their attention, and in arrays of 2 items, 4-month-old infants' looking may be more strongly influenced by faces. Alternatively, it is possible that 4-month-old infants' attention is externally controlled even in this less demanding context, and their looking will be primarily influenced by salience.

We tested infants in one of two conditions. In Experiment 2A, we paired faces with strong competitors (the flowers from Experiment 1, which were on average the most salient stimuli); in Experiment 2B, we paired faces with relatively weaker competitors (the shoes from Experiment 1, which, like faces, were rarely highly salient). These two conditions allowed us to test several possibilities. First, if the pattern of results observed for 4-month-old infants in Experiment 1 is limited to situations in which visual processes are overloaded (e.g., by large number of items in the array), then faces should immediately capture attention in both Experiments 2A and 2B. Alternatively, if the effect of salience in Experiment 1 was independent of the number of items in the array, infants' first look should be directed to the high-salience flower in the 2-item arrays of Experiment 2A, and their first looks should be equally divided to the face and the shoe in Experiment 2B. Finally, it is possible that high-level features, such as social significance, can influence young infants' looking only when there is no need to overcome physical salience. In this case, infants will look first at the flower in Experiment 2A but will look first at the face in Experiment 2B.

Method

Participants—Participants were 44 healthy 4-month-old infants (Experiment 2A: 13 boys and 11 girls, *M* = 121 days, *SD* = 5.04; Experiment 2B: 10 boys and 10 girls, *M* = 121 days, *SD* = 6.24). On average, infants contributed 10.20 trials (*SD* = 1.61) for fixations and 6.98 trials (*SD* = 1.97) for saccades.

The procedure and stimuli were identical to those described in Experiment 1A except as noted. Infants received 12 5-s trials with arrays of two items. In Experiment 2A, the items were selected from 12 face and 12 flower images, and in Experiment 2B the items were selected from 12 face and 12 shoe images (the same faces were used in both experiments). On each trial, one item was randomly selected from each of the two categories, and these two items were presented equally distant from the center of the monitor. The items were presented at 2 of the 6 locations that were used as in our previous experiments, with the constraint that the locations were 180 degrees apart (see Figure 6).

Note that we selected more or less salient *categories* (and not particular items) based on the salience values obtained for the arrays used in Experiment 1. This raises two issues. First, our salience manipulation is confounded with category. That is, in Experiment 2A, we paired faces with *flowers*, which were highly salient across all trials in Experiment 1, and in Experiment 2B we paired faces with *shoes* which were generally not more salient than faces. Given our current naturalistic stimulus set, this confound was unavoidable, and it probably corresponds to differences in average salience among categories of everyday objects that are familiar to infants. Importantly, the results of Experiment 1 provided no strong evidence that younger infants' preferences were based on the categories of items, but future research will need to unconfound these factors.

Second, the relative salience value of each item depends on the context, and can be influenced by factors such as the number of objects in an array and distance from the other objects. Thus, to confirm the relative salience of flowers, faces, and shoes in these 2-item arrays, we computed salience estimates for the stimulus pairs used in Experiments 2A and 2B as described earlier. The results are presented in Table 4. These analyses revealed that flowers were generally more salient than faces in the flower-face pairs, and neither the shoe nor the face was generally more salient in the shoe-face pairs. This was true when considering the most salient item in the array according to each toolbox, and when considering the average salience computed from the feature maps. Given that we chose shoes because they, like the faces, were not likely to be the most salient item in the arrays of Experiment 1, this is exactly the pattern we expected.

Results and Discussion

Experiment 2A—The average proportions of first fixations and first saccades directed at the face are presented in Figure 7A. Because there were only two items in each array, chance in this experiment was .50. When faces were paired with flowers, infants tended to direct their first fixations and saccades to the face *less* than expected by chance and were therefore more likely to look at the flower, $t(23) = -2.39$, $p = .025$, $d = .49$ for fixations, and $t(23) = -2.59$, $p = .017$, $d = .53$ for saccades. We also coded the data in terms of which item was more salient in a given array, independent of whether it was a face or a flower (although the most salient item was a face on only 19% of the trials). As is evident in Figure 7B, infants directed a higher proportion of first fixations, $t(23) = 3.02$, $p = .006$, $d = .62$, and first saccades, $t(23) = 3.22$, $p = .004$, $d = .66$, toward the most salient item. Comparison of the latencies of these first looks also confirmed that infants were no faster to direct a look to a face than a non-face, or to direct a look to the most salient item than to the other items (see Table 3). In summary, these 4-month-old infants showed the same pattern when presented with arrays of 2 items as did 4-month-old items presented with arrays of 6 items in Experiment 1; attention-getting was more highly influenced by physical salience than by the presence of a face. Thus, visual overload was not the reason that 4-month-old infants in Experiment 1 oriented to the most salient objects; they also exhibited this pattern when each array contained only two items.

Next, we examined attention-holding by comparing the proportion of total looking at the faces to chance (.50). A one sample t-test indicated that infants did not look at the face significantly more than expected by chance, $p = .75$. As shown in Figure 8, they devoted nearly equal proportions of their looking to the face and the flower. Similarly, infants did not spend more time looking to the most salient item (regardless of category) than expected by chance, $p = .22$. These results suggest that neither the face nor the visually salient flower holds infants' attention preferentially when there are only two items within an array. This is inconsistent with the strong attention-holding effects of faces observed in Experiment 1, and seems to contradict other findings showing that infants in this age range prefer faces to other stimuli (DeNicola et al., 2013). Importantly, we examined the effect of physical salience on infants' face preference, and this variable has not been consistently evaluated in previous studies. The effect of the physical salience of competitors on infants' face preferences will be revisited in the *General Discussion*.

Experiment 2B—Experiment 2B was essentially the same as Experiment 2A, except that faces were presented with weaker competitors (shoes) than Experiment 2A. Figure 7 shows the proportion of first fixations and first saccades directed at the face (7A) or the most salient item (7B). The pattern is quite different from that in Experiment 2A or in Experiment 1. Infants in Experiment 2B directed their first fixations, $t(19) = 2.99$, $p = .007$, $d = .67$, and first saccades, $t(19) = 2.22$, $p = .039$, $d = .50$, to the face more than expected by chance. We also compared infants' first looks to the relatively more salient (i.e., the item rank ordered as more salient when applying the saliency toolboxes) and the relatively less salient on each trial. In this case, there was no evidence that infants directed their first fixations or the first saccades toward the more salient item more than would be expected by chance (e.g., .50), first fixations, $t(19) = .51$, $p = .62$, $d = .11$; first saccades, $t(19) = .48$, $p = .64$, $d = .11$, (see Figure 7). Evaluation of the latencies of the first looks again revealed no difference in how quickly infants' directed their first look to faces versus the shoe, or to the item that was relatively more salient (see Table 3). Thus, in this context—in which faces were presented with a single weak competitor—infants looked first at the faces, and this preference reflects a preference for faces per se rather than being a consequence of physical salience.

Faces also held infants' attention more strongly than did shoes in this experiment (see Figure 8). The proportion of looking directed toward faces was significantly greater than chance, $t(19) = 4.57$, $p < .001$, $d = 1.02$. In contrast, the proportion of looking directed at the physically salient item was not greater than would be expected by chance, $t(19) = .396$, $p = .70$, $d = .09$.

Comparison of Experiments 2A and 2B—We next conducted across-experiment *t* tests to determine whether the patterns of looking behavior differed significantly between Experiments 2A and 2B. There was a significantly greater proportion of first fixations to the face in Experiment 2B (when it was paired with a shoe) than in Experiment 2A (when it was paired with a flower), $t(42) = 3.85$, $p < .001$, $d = 1.19$. Similarly, a significantly greater proportion of first saccades were directed at faces in Experiment 2B than in Experiment 2A, $t\ (42) = 3.39$, $p = .002$, $d = 1.05$. Recall that these differences mean that infants were more likely to initially look at exactly the same face when it was paired with a weak competitor (i.e., the shoes which based on our salience analysis were similar in salience to the face, on average, Experiment 2B) than when it was paired with a strong competitor (i.e., the flower which was a highly salient, Experiment 2A). Thus, *attention-getting* processes are determined not only by the features of the target stimuli (the faces in this case), but by the features of the competitors in the array.

In addition, we compared the latencies of the first looks in these two experiments (collapsed across the particular type of stimulus to which those first looks were directed). As is evident from the means presented in Table 3, infants in Experiment 2B were significantly slower to fixate an item than were infants in Experiment 2A, $t(42) = 2.99$, $p = .005$, $d = .92$. That is, when presented with pairs of items, infants fixated one of the items faster when the pair contained a highly salient item. Even though these infants were not faster to fixate the most salient item in the array, the presence of a highly salient item appears to have induced faster initiation of a fixation. Of course, this analysis is ad hoc, and the conclusions are speculative. But, they provide additional support for the general conclusion that attention-getting is influenced by features of the competitors.

The two experiments also yielded different results for attention-holding. A higher proportion of looking was directed at faces in Experiment 2B than in Experiment 2A, $t(42) = 3.37$, $p = .002$, $d = 1.04$. It appears that infants have more difficulty maintaining their looking to the face when the competing stimulus is highly salient; when the face is more salient or the difference in salience is more modest, infants can maintain their looking to the face for longer durations of time. In other words, like attention-getting processes, attention-holding processes are influenced by the competing stimuli.

General Discussion

This study was designed to examine the development of infants' visual attention in multi-item arrays. We asked how the low-level features (physical salience) and high-level features (social relevance) of individual items contributed to attention-getting and attention-holding processes when 4- to 8-month-old infants viewed scenes containing 2 or 6 complex objects. The results of this study provide converging evidence for a general developmental change in which higher-level features have an increasing impact on attentional control in older infants (Johnson, 2010; Ruff & Rothbart, 1996). In addition, the results provide new evidence concerning the control of attention in 4-month-old infants. Specifically, 4-month-old infants' preference for social stimuli in these arrays was highly influenced by the characteristics and number of competitors. The significance of these findings is discussed in the following paragraphs.

First, these findings are important because they show that previously observed developmental changes in infants' preferences for faces can be generalized to more complex visual arrays that contain highly salient non-face objects. Specifically, we found that infants 6 months and older have robust preferences for faces in arrays that contain many complex objects and objects that are substantially more salient than the faces. As observed in other studies (Di Giorgio et al., 2012; Frank et al., 2009, 2014; Gliga et al., 2009; Gluckman & Johnson, 2013), faces held 6- and 8-month-old infants' attention for longer durations than did competitors, even when those faces were not the most salient items. In addition, we observed that these older infants directed their first looks at faces more than at competitors, indicating that these socially relevant stimuli could be detected using peripheral vision and could then control attentional orienting. Thus, faces both capture and hold infants' attention as early as 6 months. By 6 months, therefore, eye gaze is similar to that exhibited by adults during free viewing of scenes.

The results from our 4-month-old infants are consistent with other research, particularly studies using relatively crowded or cluttered visual arrays. As observed by Di Giorgio et al. (2012), our 4-month-old infants in Experiments 1A and 1B—in which the arrays contained 6 items—did not look first at the socially-relevant face. Instead, similar to findings reported by Frank et al. (2009), our 4-month-old infants were drawn to regions of high salience, looking first and longer at the most salient item. Although these younger infants did also look longer at the face than expected by chance, their face preference was reduced relative to that of older infants, suggesting their looking is influenced by a combination of multiple factors. Indeed, in Experiments 2A and 2B, in which we presented infants with pairs of items, both the social relevance (i.e., the face) and the physical salience contributed to infants' looking.

This general developmental pattern is consistent with developmental changes in attentional control allowing an increasing ability to suppress salient but irrelevant information (Johnson, 2010; Ruff & Rothbart, 1996). That is, attention-getting and attention-holding were strongly influenced by low-level features (i.e., physical salience) in younger infants, whereas 6- and 8-month-old infants appeared to better inhibit the low-level information and direct attention to the face. Althaus and Mareschal (2012) reported a similar developmental trajectory in their evaluation of infants' fixations to highly salient regions versus potentially diagnostic regions during category learning. In general, they found that younger infants were more focused on low-level features than were older infants. The younger infants were initially drawn to salient regions and later looking at the center of the stimulus, whereas 12-month-old infants, who were also initially drawn to highly salient regions, shifted their looking to potentially informative regions (i.e., the antlers of deer during a category task with deer stimuli). Despite differences in method and stimuli, both the current findings and these previous findings point to differences in the kinds of features that attract older and younger infants' visual attention.

The four experiments reported here together also indicate that the control of gaze in 4-month-old infants reflects contributions from both high-level factors (social relevance) and low-level factors (salience), which also interact with the overall attentional demands of the stimulus array (the number of objects in the array). Specifically, we observed that infants' attention depended on whether one item was a face, the difference in salience between the items, and the number of competing items. For example, the relatively salient item was effective at attention-getting both in the 6-item arrays of Experiment 1 and the 2-item arrays of Experiment 2A, but had a stronger impact on attention-holding in the 2-item arrays of Experiment 2A. Thus, the same non-face competitor could be more or less effective at distracting infants from their looking at the same face, depending on the number of items in the array. Comparison of Experiments 2A and 2B revealed that the same face could capture and hold infants' attention in 2-item arrays when paired with a relatively weak competitor (the shoe), but not when paired with a stronger competitor (the flower). Taken together, these results demonstrate that young infants are sensitive to both social relevance and physical salience and that both of these factors interact with the degree of salience and the overall number of items in the array. Thus, the development of gaze control is not characterized by simple "stages", in which gaze is controlled by salience at some ages and social relevance at other ages. Instead, multiple processes interact to determine whether attention is attracted and/or held by a given object in a given array.

This interpretation of our findings also points to the possible source of discrepancies in previous studies. For example, Gliga et al. (2012) and Di Girorgio et al. (2012) both observed 6-month-old infants' preference for faces in 6-item arrays; Gliga et al. found faces to be effective at attention-getting in 6-month-old infants, whereas Di Giorgio et al. did not. Because the individual stimuli differed—and the researchers did not report the physical salience of non-face objects—it is possible that differences in results reflect differences in the physical salience of the stimuli used. Moreover, De NiCola et al. (2013) did not find an attention-getting effect of faces in 2-item arrays even for older infants. The present results suggest that the attention-getting effects of faces in such arrays depend on the salience or strength of the competitor.

Then, how does the number of competitors influence infants' looking? One possibility is that the number of competitors simply impacts the relative salience of the individual items. Increasing the number of non-face competitors will make the most salient item pop-out less than when a face is presented with only one non-face competitor in the array. In addition, the number of items in the display determines the overall distribution of saliency, because salience values of objects are determined by neighboring objects. Another possibility is that increasing the number of competitors may have placed greater demands on infants' developing ability to inhibit responses to competing stimuli. Given previous research, we would anticipate that our 4-month-old infants would have relatively poorly developed attentional control, particularly in terms of inhibiting responding to stimuli with high "attend-to-me" signals (Johnson, 2010; Ruff & Rothbart, 1996). When there are multiple competitors, there are more items to inhibit, which may be particularly challenging for young infants. These three possibilities are not mutually exclusive, and it would not be surprising if the pattern we observed in 4-month-old infants reflects all of these factors.

It is important to point out that in our experiments salience was confounded with object category. That is, *in general*, the flowers we used were the most salient items in our arrays, whereas the faces and shoes were the least salient. Although we cannot completely rule out the possibility that some of the effects observed in the present study reflect category effects rather than differences in salience, there are reasons why salience is likely to be the key factor. First, although flowers were generally more salient, they were not always the most salient. Similarly, faces and shoes were occasionally the most salient items. When we conducted studies examining the effects of salience, we classified items based on salience, *regardless of the category*. Moreover, our additional analyses of infants' looking toward the flower did not reveal robust effects, like those observed when analyzing the same data in terms of infants' looking to the most physically salient item. Therefore, across infants, the preference for the most salient item was not a preference for a particular category, but a preference for the most physically salient item regardless of the category. Third, we found that older infants preferred faces regardless of salience, and that younger infants exhibited little or no preference for faces in the presence of a high-salience distractor. We reasoned that if infants had a strong intrinsic interest in any category, it would be for faces. However, younger infants had a difficult time directing and maintaining their attention to faces when a highly salient competitor was present.

The present results are important because of their implications for the broad literature on the factors contributing to infants' preferences for social stimuli. There has been significant interest in infants' face processing, and the conditions that lead infants to show robust preferences for faces (e.g., Di Giorgio et al., 2012; Frank et al., 2009, 2014; Gliga et al., 2009; Gluckman & Johnson, 2013). Research has revealed that although newborns and young infants do show preferences for human faces, these preferences seem to reflect preferences for lower-level stimulus features, such as symmetry and top-heaviness (i.e. more elements in the top compared to the bottom part of the face) (Cassia, Turati, & Simion, 2004; Cassia, Valenza, Simion, & Leo, 2008; Farroniet al., 2005; Kleiner, 1987), rather than a preference for faces per se. Indeed, there is evidence that infants' face preferences change over the first year as a function of their extensive experience with human faces (versus monkey faces, Pascalis, de Haan, & Nelson, 2002) or with faces of a particular race (Kelly et al., 2005; Kelly et al., 2007). This body of work suggests that infants' face preferences reflect perceptual processes that are shaped by experience.

Nevertheless, researchers have argued that from a very young age infants recognize social stimuli and attend to such stimuli to understand the social significance of acts, images, and events (e.g., Chevallier et al., 2012; Gluckman & Johnson, 2013; Meltzoff, 2007). For example, Meltzoff (2013) argues that a primitive of social cognition is the recognition or sense of "like me" when viewing human faces. He argues that from birth infants have a sense of similarity to others triggered by seeing a face. According to this perspective, therefore, infants' preferences for social stimuli—and perhaps faces, in particular—stems from an early emerging understanding of the nature and significance of human faces.

Our results suggest that infants' preferences (or lack of preferences) for social stimuli reflect a complex set of factors, and the interaction among those features changes with development. Specifically, to the extent that infants' preference for faces at any age reflects an interest in socially relevant features, this preference can only be expressed as a function of infants' ability to balance a number of competing influences on attention. That is, selecting a socially relevant stimulus requires attentional control to inhibit responding to other features of the environment and to focus on specific items. It is possible that 4-month-old infants recognize the social relevance of the faces, but that their attentional control abilities are not sufficiently developed to allow them to inhibit responding to other features, such as low-level physical salience. Alternatively, it is possible that attentional control in 4-month-old infants is not yet influenced by social relevance. This second possibility seems unlikely given evidence that faces held their attention. However, it is possible that the mechanisms governing attention-getting are not yet influenced by social relevance. The present results cannot differentiate these possibilities, but they do show that even attention to highly relevant stimuli, such as faces, is complexly determined in infancy.

Finally, the experiments presented here contribute to how we think about and measure *salience* in studies of infant visual attention. We used three different computational models known to predict adults' looking behaviors so that we could better determine the relative salience of the items in our displays. Two things are clear from this analysis. First, the three models only had modest agreement, with the same item or region being rated the most salient by at least two models in only approximately 2/3 of our visual arrays. This modest agreement is not surprising given findings that the models are differentially effective at predicting adults' looking behaviors under different conditions (Koehler et al., 2014). Moreover, the computational models are based on different weightings of different sets of features, such as color, brightness, and orientation (Zhao & Koch, 2013).

However, it is also clear from our saliency analysis that these models were effective at predicting young infants' looking. Thus, even though none of the models may perfectly match the infant visual system's computation of salience, the combination of models is sufficiently close that it can significantly predict infants' looking behavior. Our ability to account for infants' eye movements is particularly remarkable given that these models were developed on the basis of *adult* visual processes (e.g. Bruce & Tsotsos, 2009; Itti & Koch, 2000). Given the significant changes in visual processing (e.g. visual acuity, sensitivity to color contrast) during infancy (Adams, 1987; Dobson & Teller, 1978; Sokol, 1978), it is likely that features influence salience differently across development. Nevertheless, the salience models successfully predicted attention-getting and attention-holding in infants, suggesting that factors such as orientation, brightness, and color influence infants' attention. One goal for future research is to better understand how salience should be quantified and described in infancy.

In summary, the present investigation contributes to our understanding of developmental changes in infants' selective attention for social stimuli (faces) over other stimuli. By 6 months, infants have a robust preference for faces even in complex arrays with many highly salient competitors. At 4 months, however, infants' face preference is less robust and varies as a function of the measure, the demand on attentional resources, and the characteristics of the competing stimuli. Thus, the present results are consistent with the conclusion that infants' developing preference for faces, and perhaps other socially relevant stimuli, reflects, at least in part, their developing attentional processes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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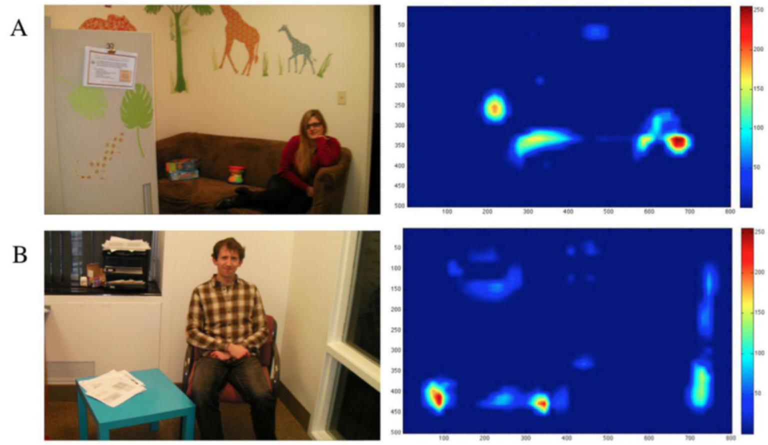


Figure 1.

Examples of stimuli (left side) and salience maps of those stimuli (right side) adapted from "An eye tracking investigation of developmental changes in bottom-up attention orienting to faces in cluttered natural scenes," by D. Amso, S. Haas, & J. Markant, 2014, *PLoS ONE*, *9*(1), e85701, p. 3. Used under a Creative Commons (CC-BY) license. The red spots correspond to the region of highest salience.

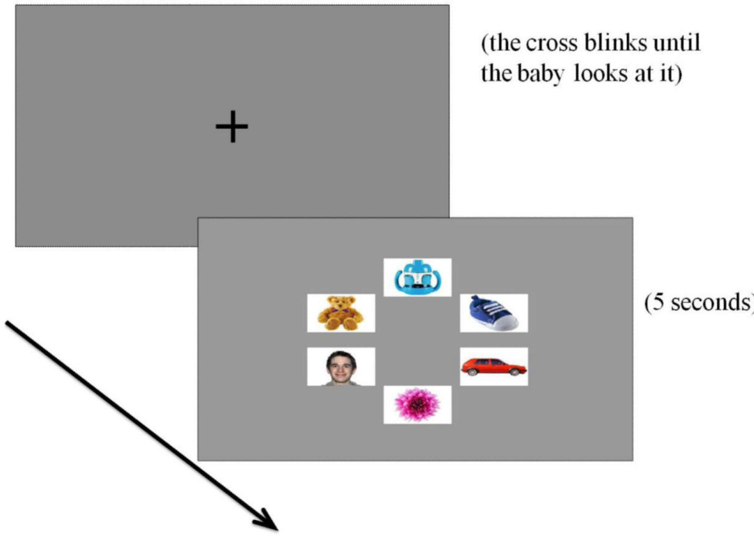
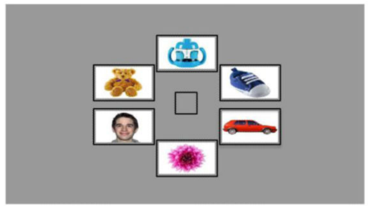
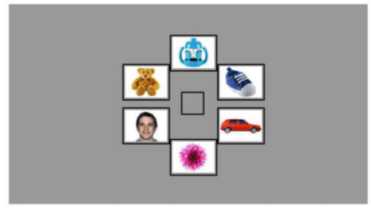


Figure 2.

Schematic depiction of a trial and display from Experiment 1 (main experiment). The face image was obtained from the NimStim Face Stimulus Set (Tottenham, Tanaka, Leon, McCarry, Nurse, Hare, et al., 2009) with permission from the authors. The authors received signed consent for his likeness to be published in scientific journals from the individual whose face appears here.



(Experiment 1A: main)



(Experiment 1B: replication)

Figure 3.

Sample displays with AOIs from Experiment 1. The AOIs for the stimulus locations and the center are indicated by black boxes in the figure (these boxes were not shown to the infants). The face image was obtained from the NimStim Face Stimulus Set (Tottenham et al., 2009) and the individual whose face appears here gave signed consent for his likeness to be published in scientific journals.

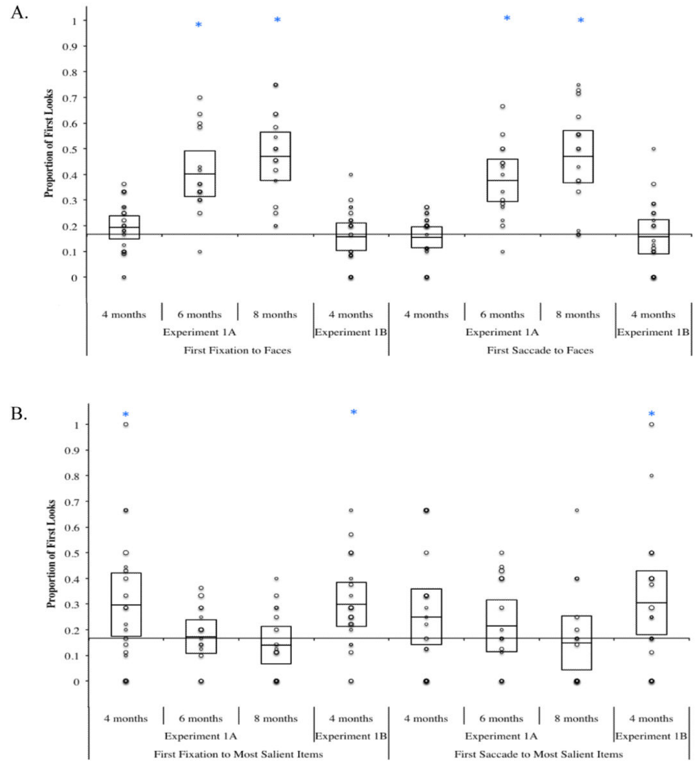


Figure 4.

Mean proportions of first fixations and first saccades to the face (A) or to the most salient item as determined by an agreement of at least 2 toolboxes (B). Chance level, indicated by the horizontal line, was .167, and means that differed significantly from chance ($p \leq .05$) are indicated by an asterisk. Each individual circle represents the change preference for a single infant. The bar bisecting the boxes reflects the mean and the boundaries of box reflects the 95% confidence interval for that mean.

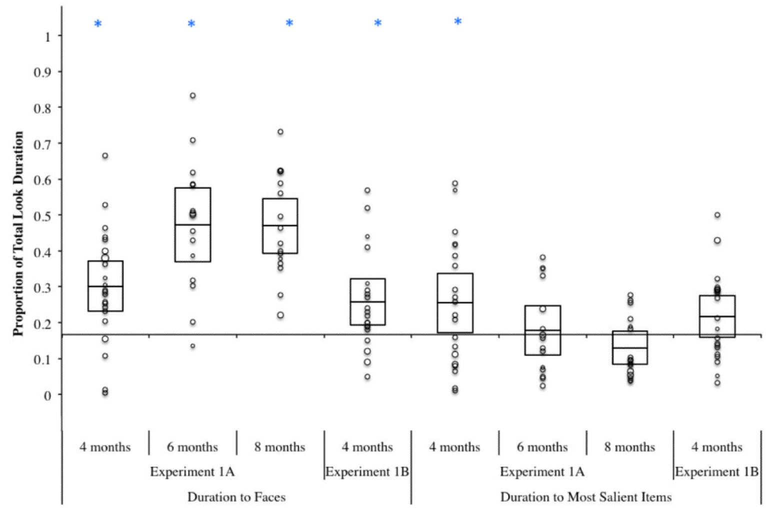


Figure 5.

Mean proportions of durations of looking to either the face (A) or most salient item (B) in each array for the main experiment (trials 5 s in duration) and the replication (trials 12 s in duration). Means that were significantly different from chance (.167) are indicated by * *p* <. 05.

Figure 6.

Examples of stimulus arrays in Experiments 2A (left) and 2B (right). The face image was obtained from the NimStim Face Stimulus Set (Tottenham et al., 2009) and the individual whose face appears here gave signed consent for his likeness to be published in scientific journals.

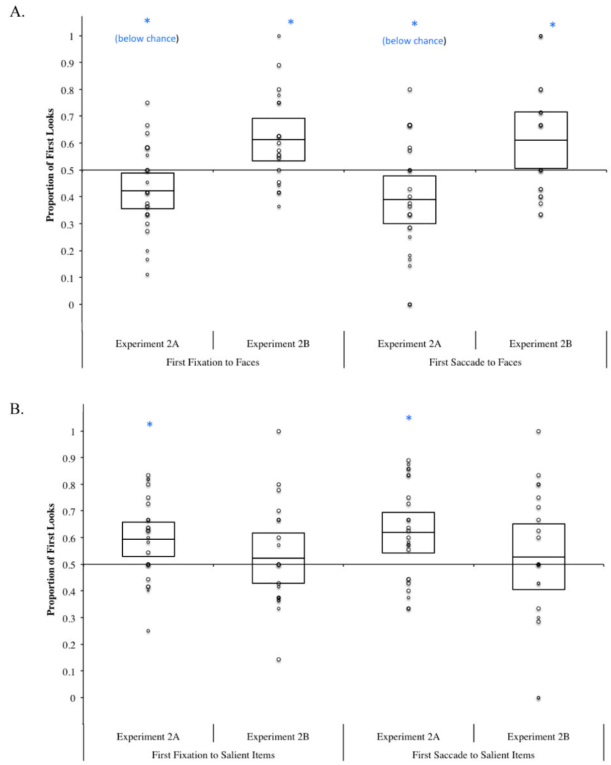


Figure 7.

Infants' first looks and first saccades to the face (A) and salient item (B) in each array of Experiments 2A and 2B. Chance level, indicated by the horizontal line, was .5; means that differed significantly from chance are indicated by an asterisk, $p < .05$. Each individual circle represents the score for an individual infant. The bar bisecting the boxes reflects the mean and the boundaries of box reflects the 95% confidence interval for that mean.

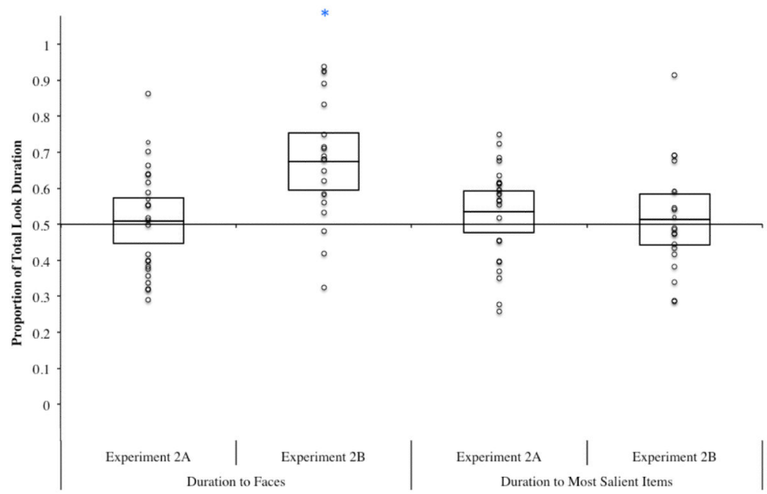


Figure 8.

Proportion of infants' looking duration directed to the face and most salient item in each array of Experiments 2A and 2B. Means that were significantly different from chance (.50) are indicated by * *p* <.05.

Table 1

Number of participants excluded from final analyses by experiment, infant age, and reason for exclusion

Experiment	Age	Total	Reason for Exclusion		
			Experimenter error or equipment malfunction	Failure to calibrate	Failure to provide sufficient useable data[a]
1A	4	7	2	1	4
	6	5	3	1	1
	8	4	0	1	3
1B	4	15	2	4	9
2A	4	5	0	1	4
2B	4	22	1	14[b]	7

[a]The most common reason for this was the infant became too fussy to continue

[b]This unusually high rate of calibration failures probably reflects our experimenter’s adjusting to the new ASL optics. Importantly, the infants in this experiment did not differ from the other experiments in any significant way (e.g., age, number of trials completed).

Table 2

The proportions of trials for each category that were the most salient in the given arrays as determined by each toolbox independently (GBVS, IK, AIM), as well as the proportions for the subset of trials on which at least two toolboxes converged on the most salient item (Convergence). Regardless of how physical salience was established, *faces* were the least likely to be the most salient item in the array.

		# of trials	Flower	Bear	Car	Sippy	Shoe	Face
Experiment 1A								
	Convergence	359	0.47	0.18	0.08	0.21	0.06	0.01
	GBVS	549	0.46	0.24	0.10	0.11	0.05	0.04
	IK	549	0.36	0.24	0.09	0.19	0.10	0.01
	AIM	549	0.22	0.07	0.28	0.32	0.08	0.02
Experiment 1B								
	Convergence	135	0.48	0.15	0.10	0.17	0.10	0.00
	GBVS	205	0.45	0.23	0.12	0.13	0.05	0.02
	IK	205	0.36	0.23	0.13	0.11	0.17	0.00
	AIM	205	0.24	0.09	0.21	0.30	0.11	0.05

Table 3

Mean first fixation latency (in s) by Experiment, age, and type of stimulus.

Latencies by stimulus category (Face vs. Non-face)				
Experiment	**Age**	**N[a]**	**Trial Type**	
			Faces	**Non-Face items**
1A	4	20	0.87 (0.48)	0.91 (0.32)
	6	15	0.97 (0.41)	0.85 (0.30)
	8	16	0.77 (0.32)	0.69 (0.23)
1B	4	17	1.20 (0.80)	1.04 (0.55)
2A	4	24	0.73 (0.30)	0.79 (0.38)
2B	4	19	1.14 (0.70)	1.12 (0.57)
Latencies by relative salience (Most salient vs. Others)				
Experiment	Age	N[a]	Trial Type	
			Most Salient Item	All others
1A	4	16	1.20 (0.93)	0.83 (0.32)
	6	12	1.00 (1.09)	0.84 (0.35)
	8	9	0.61 (0.16)	0.81 (0.28) [b]
1B	4	18	1.07 (1.20)	0.99 (0.57)
2A	4	24	0.71 (0.30)	0.79 (0.38)
2B	4	19	0.99 (0.45)	1.18 (0.65)

[a] *Note*: Because some infants only looked at the face or never looked at the face, the *Ns* vary in these comparisons.

[b] The only comparison that differed was the 8-month-old infants' latencies for first fixations to most salient item to all others. These infants looked faster on the few trials they looked first to the most salient item, $p < .05$.

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Table 4

The proportions of trials for which a given category was the most salient in the stimulus arrays.

	Experiment 2A			Experiment 2B		
	# of trials	**Face**	**Flower**	**# of trials**	**Face**	**Shoe**
Converging	260	0.19	0.81	189	0.59	0.41
GBVS	260	0.26	0.74	189	0.71	0.29
IK	260	0.14	0.86	189	0.33	0.65
AIM	260	0.44	0.56	189	0.62	0.38