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The Role of Shape Recognition in Figure/Ground Perception in Infancy

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Abstract

This study sought to determine whether infants, like adults, utilize previous experience to guide figure/ground processing. After familiarization to a shape, 5-month-olds preferentially attended to the side of an ambiguous figure/ground test stimulus corresponding to that shape, suggesting that they viewed that portion as the figure. Infants' failure to exhibit this preference in a control condition in which both sides of the test stimulus were displayed as figures indicates that the results in the experimental condition were not due to preference between two figure shapes. These findings demonstrate for the first time that figure/ground processing in infancy is sensitive to top-down influence. Thus, a critical aspect of figure/ground processing is functional early in life.

Keywords

figure/ground perception; top-down processing in infancy; attention; perceptual organization in infancy; top-down influences on figure/ground perception

Infants frequently encounter complex stimulus arrays in their visual environment. Thus, they are in need of efficient ways to scan and extract relevant information from the noise. Figure/ground parsing is a critical mechanism for focusing the viewer on the relevant information in a scene. Generally, objects, especially those that afford interaction, become the figure and the remaining space becomes the ground. Previous research with infants has examined the features that lead to a shape being seen as a figure (Takashima, Kanazawa, Yamaguchi, & Shiina, 2014), but, to our knowledge, no study has examined the role of experience in figure/ground distinctions in infancy. The current study examined whether, like adults (Peterson & Gibson, 1991), infants use shape recognition to parse figure from ground in ambiguous displays. Specifically, after familiarization to a novel shape, do infants treat a corresponding portion of an ambiguous shape as the figure? Such a finding would demonstrate that some top-down influences on figure/ground segmentation are present early in life.

Many prominent theories of figure/ground perception suggest that objects can be recognized only after the figure has been detected and segregated from the background (Beiderman, 1987; Marr, 1982). This means that the predominant factors contributing to figure/ground

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distinctions would be stimulus-level features. This view is supported by research demonstrating that a variety of gestalt principles such as symmetry (Driver, Baylis, & Rafal, 1992), enclosure (Taya & Ohashi, 1992), and area (Palmer, 1999) systematically impact figure detection. However, it has been shown that top-down processing also plays a role in figure/ground parsing. For example, Peterson and Gibson (1991) presented adults with a stimulus containing two shapes either of which could be considered the figure or the ground. One shape was familiar (e.g., a face) and the other was not. Adults identified the familiar shape as the figure more often than the non-familiar shape. Such findings of shape recognition influencing figure/ground parsing has been replicated many times (Navon, 2011; Peterson & Gibson, 1994; Peterson, Harvey, & Weidenbacher, 1991; for review see Peterson, 1994). Thus, adults clearly utilize shape recognition during figure/ground parsing; however, it is unclear if this ability is present early in life.

Research on figure/ground perception in infancy has emphasized action perception and utilized dynamic stimuli to examine the relationship between motion cues and figure/ground perception (Arterberry, Craton, & Yonas, 1993; Ross-Sheehy, Perone, Vecera, & Oakes, 2016). To our knowledge, few studies have examined the use of static cues in figure/ground perception by infants. One study found that, similarly to what has been shown with adults (Peterson & Salvagio, 2008), decreased homogeneity of the background impairs infants' ability to perceive a shape as the figure (Takashima et al., 2014). Specifically, in Rubin's goblet illusion (perceived as two faces or a vase), when the faces were different shades of gray infants were unable to perceive the goblet as the figure. Thus, infants' perception of figure/ground can be systematically impacted by non-kinetic stimulus features.

Scanning patterns are a sensitive metric of infant knowledge and development. For example, scanning of static geometric figures becomes more complex with age (Bronson, 1994): older infants show more between-figure comparisons than younger infants. Furthermore, scanning of typical household pets becomes more efficient with increased experience with these pets (Kovack-Lesh, McMurray, & Oakes, 2014). Together, these findings demonstrate how scanning patterns differ based on maturation and experience. Therefore, experience may also affect systematic scanning of ambiguous figure/ground stimuli in infancy. Furthermore, adults direct their attention to the figure as opposed to the ground when viewing images (Mazza, Turatto, & Umilta, 2005; Nelson & Palmer, 2007; Zhang, & Sclaroff, 2013). Therefore, if infants utilize previous knowledge to make figure/ground distinctions when processing ambiguous stimuli, they should attend more to the learned figure than to the ground.

Thus, the goal of the current study was to determine whether, as in adulthood, object recognition impacts figure/ground perception in infancy. Infants were familiarized to a shape and then presented with an ambiguous test image containing the contour of the familiarized image. The ambiguous figure was such that both sides of the contour could be perceived as the figure or the ground, while only one matched the familiarization image (Figure 1). If infants attend more to the side of the image matching the familiarization image, then it would be evidence that infants apply previous experience when making figure/ground distinctions in ambiguous stimuli. Such a finding would be indicative of adult-like top-down influence on figure/ground perception early in life.

However, infants may not perceive the ambiguous image as a figure that matches the familiar shape surrounded by a shapeless ground. Instead, while there is no precedent to suggest this is the case, they could view both sides of the ambiguous image as figures and look toward the familiar shape side because of a familiarity preference. Although infants normally exhibit a novelty preference after a familiarization procedure of the sort used in the current study, they sometimes exhibit a familiarity preference (Galati, Hock, & Bhatt, 2016; Johnson et al., 2009). Therefore, infants' performance may be due to a familiarity preference between shapes. To address this possibility, infants in a control group were shown test stimuli that clearly include two figures instead of an ambiguous shape. Specifically, infants in this condition were familiarized to shapes in exactly the same manner as infants in the experimental condition, but were tested with two explicit shapes: one that matched the familiar shape and another that matched the opposite side of the ambiguous image (Figure 1). If infants' performance in the experimental condition is due to a familiarity preference, infants in the control condition should behave similarly. If, however, there are differences in performance between the experimental and control conditions, then it would suggest that infants were treating the ambiguous stimulus as if it had only one figure and that their previous experience guided the figure/ground distinction.

Method

Participants

Thirty-two 5-month-old infants, 16 in the experimental/ambiguous condition (mean age=150.63 days, *SD*=6.01; 7 female) and 16 in the control/two-shape condition (mean age = 151.06 days, *SD*=5.95; 6 female), were included in the final sample. Data from additional participants were excluded for looking at the stimuli for less than 15% of the test duration (*n*=9). This a priori criterion is similar to that commonly used in eye-tracking studies with infants (Merin, Young, Ozonoff, & Rogers, 2006; Taylor & Herbert, 2013). Infants were also excluded for failing to sample both stimuli (*n*=3), equipment failure (*n*=1), fussiness (*n*=1), or being an outlier as defined by having looking scores greater than 1.5X the interquartile range beyond the 1^{st} or 3^{rd} quartile (*n*=2). Participants were recruited from birth announcements and a local hospital, and were predominantly Caucasian.

Stimuli

Experimental Ambiguous Condition—All images were created in Adobe Photoshop. For each set of familiarization stimuli, a solid red rectangle was divided to generate two shapes (Figure 1). Notice that the shapes differ in their parts, but have an identical unique (stepped) contour. Half of the infants were familiarized to one of the shapes and the other half were familiarized to the opposite shape. Then, all infants were tested with the same ambiguous test images that were created by placing the unique contour (identical for both shapes) in a white box on a gray background (Figure 1). In the ambiguous images, the white space on either side of the contour can be seen as either the figure or the ground. As the test images were the same for both corresponding shapes, preferential looking to one side of the contour cannot be attributed to low level features (e.g., protrusion). In other words, across infants, the two sides of the ambiguous test figures were equally often the familiar shape, so that performance during the test cannot be attributed to anything idiosyncratic about one side. Two sets of familiarization and test images were created using this method. Additionally, to prevent biases to look to a single side from skewing performance, all of the images were flipped about the horizontal axis to make a total of 8 familiarization shapes and four test images. Familiarization and test images seen by individual infants were also flipped about the vertical axis so that the unique contour appeared on the left or right side of the shape equally often. On average stimuli subtended a horizontal and vertical visual angle of 23.24° and 13.60° respectively.

Control Two-shape Condition—Familiarization stimuli were the same as in the ambiguous condition. Test stimuli were created by removing the black line and separating the remaining white shapes (Figure 1). This resulted in two white figures situated on a gray background.

Apparatus and Procedure

Infants were seated on a parent's lap in a darkened chamber, approximately 65 cm in front of a 58 cm computer monitor. Parents wore opaque glasses and were instructed to not direct their infant's looking in any way. Each infant experienced four 15-s familiarization trials (one shape in two orientations, Figure 1) followed by four 10-s test trials (in which they were tested on a single contour in two orientations in the experimental condition and two different shapes in two orientations in the control condition, Figure 1). Preceding each trial, an attention getter (alternating shapes) appeared on the center of the screen. When the infant looked at the center of the screen (as judged by a live video feed) the researcher pressed a key to advance to the next trial. The left/right location of the unique contour alternated from familiarization trial 1 to familiarization trial 2, and the pattern reversed for each of the remaining familiarization and test trials (see Figure 1 for an example). Thus, the left(L)/ right(R) pattern for half of the infants was (LRRLLRRL) and for the other half it was (RLLRRLLR). Left/Right location for the first familiarization trial and first test trial was counterbalanced across infants and shapes.

A Tobii TX300 eye-tracker was used to record infants' looks. Before starting data collection, each infant's eyes were calibrated using a 5-point infant calibration procedure in which a rattle coupled with a rhythmic sound was presented sequentially at the four corners and center of the screen. A key press was used to advance to the next calibration point after the infant was judged (via a live video feed) to be looking at the current calibration point. The calibration procedure was repeated if calibration was not obtained for both eyes in more than one location. Calibration and stimulus presentation were controlled by Tobii Studio 3.3.1 software. The Tobii Studio fixation filter was used to classify valid fixations (defined as any look that exceeded 60ms while remaining within a 0.5° radius). This criterion removes noise from the data, such as sporadic eye movements and is similar to the criteria used in prior studies of infants' scanning (Xiao et al., 2014).

Two areas of interest (AOIs) were drawn on each of the test images. In the experimental condition, each AOI encompassed the white area on one side of the contour. AOIs were identical in size. Based on the familiarization shape a given infant saw, the AOI covering the side of the image that matched the familiarization shape was designated "figure" and the other "ground." In the control two-shape condition, AOIs encompassed the two separate shapes. Note that due to counterbalancing the "figure" AOI for one half of the infants was the "ground" AOI for the other half and vice versa in both conditions. The dependent measure was proportion fixation duration to the "figure" AOI, which was calculated by dividing the total fixation duration to the "figure" AOI across both test trials by the sum of the fixation durations to the "figure" and "ground" AOIs on both test trials. It was expected that infants in the experimental condition, but not the control condition, would attend more to the side of the contour they perceive as the figure, resulting in a preference score that is significantly greater than 50% chance.

Results

Average accumulated fixation durations during familiarization did not differ systematically between the experimental (M=28.73s, SD=2.61) and the control (M=31.21s, SD=2.65) conditions, $t(30)=0.67$, $p=.51$, $d=0.24$. During the test trials, only infants in the experimental condition attended more to the portion of the ambiguous image that matched the familiarization shape (the "figure"; Figure 2). An independent samples t-test comparing the proportion fixation duration to the "figure" AOI in the experimental ambiguous condition (M=59.18%, SE=3.45) to that in the control two-shape condition (M=41.29%, SE=4.44) found a significant difference between the groups, $t(30)=3.18$, $p=.003$, $d=1.13$. A one-sample t-test comparing the proportion fixation duration of the infants in the ambiguous condition to chance (50%) found that infants fixated on the "figure" AOI for a significantly greater amount of time than would be predicted by chance, $t(15)=2.66$, $p=.02$, $d=0.67$. Conversely, infants in the two-shape condition displayed a proportion fixation duration to the "figure" AOI which did not differ from chance, $t(15)=-1.96$, $p=.07$, $d=0.49$. Thus, infants in the control condition exhibited a non-significant tendency to prefer the "ground" during the test, whereas those in the experimental condition looked significantly longer at the "figure" portion of the ambiguous image that matched the familiar shape. These results demonstrate that object familiarity systematically impacts infants' figure/ground distinctions when presented with ambiguous displays, and such performance is not driven by a simple familiarity preference between two different shapes.

However, as pointed out by a reviewer, it is possible that performance differences in the experimental versus control conditions were due to task difficulty. Namely, the interlocking nature of the test stimuli in the experimental condition could have rendered them less discriminable, resulting in a familiarity preference between two figures (rather than a preference between figure and ground) as opposed to a novelty preference in the control condition where the stimuli were more clearly defined. While this alternative explanation is clearly a possibility, the following analysis renders it unlikely. Recall from the previously cited literature that adults are predisposed to attend to figures rather than to the background in displays (Mazza, Turatto, & Umilta, 2005; Nelson & Palmer, 2007; Zhang, & Sclaroff, 2013). If infants in the experimental condition were interpreting the ambiguous display as containing only one figure it would be expected that their preference for the figure over the ground would be greater than infants' preference between two clearly distinct figures such as those presented in the control condition. Conversely, if infants were exhibiting a familiarity preference between two figures in the experimental condition and a (non-significant) novelty preference between two figures in the control condition, then there would be no expectation of differences in the magnitude of preferences across conditions.

Accordingly, a difference score was calculated for each infant by taking the absolute value of the difference between their summed fixations over all trials to the "figure" and their summed fixation over all trials to the "ground." An independent-samples *t*-test demonstrated that infants in the experimental condition showed significantly greater difference scores (M=3.52; SE=0.62) than infants in the control condition (M=1.53; SE=0.35), $t(30)=2.80$, $p=.009$, $d=0.99$. Thus, infants in the experimental condition treated the two sides of the ambiguous test images differently than did the infants in the control condition, as one would expect if infants in the control condition were treating both shapes as figures resulting in more competition for attention, while infants in the experimental condition were interpreting one side of the ambiguous image as the figure. The difference scores analysis therefore supports the interpretation that infants in the experimental condition responded to a figure/ground contrast while those in the control condition responded to a figure/figure contrast.

Discussion

The current study found that, as with adults, shape familiarity impacts 5-month-old infants' processing of stimuli in which the figure/ground distinction is ambiguous. After familiarization to a shape, infants looked longer to the side that matched this stimulus rather than to the opposite side even though each side could be the figure or the ground. This finding indicates that infants segregated the figure from the ground based on prior experience with one of the possible images. Moreover, a familiarity preference between different shapes in the experimental condition is unlikely to explain the results because similarly trained infants in the control two-shape condition did not exhibit such a preference. Moreover, the absolute degree of preference was greater in the experimental than in the control condition, suggesting that infants viewed the ambiguous images as figures/grounds rather than as two separate figures. Thus, not only is figure/ground processing in infancy systematic, but it is sensitive to top-down influences, namely shape recognition. To our knowledge, this is the first study to demonstrate top-down influences on figure/ground processing in infancy.

As previously mentioned, research on figure/ground processing in infancy has found that kinetic cues (Arterberry, Craton, & Yonas, 1993; Craton, 1992; Kaufmann-Hayoz, Kaufmann, & Stucki, 1986) and low-level stimulus features (Takashima et al., 2014) impact figure/ground perception early in life. Moreover, studies that have examined several aspects of object perception in infancy (for reviews, see Arterberry, 2001; Bhatt & Quinn, 2011; Bremner, 2007; Johnson, 2009) suggest that infants segregate figure from ground with low-level stimulus cues. The finding in the current study that infants as young as 5 months utilize prior experience to process figure/ground information adds to this literature by showing that top-down factors also play a role in the segregation of objects from their surroundings early in life.

Scenes that infants typically experience are likely to possess several types of figure/ground cues; thus, future work should determine how such cues interact with one another. For example, research suggests that consistent top-down (e.g., object familiarity) and bottom-up (e.g., symmetry) cues can facilitate adults' figure/ground segregation while conflicting cues can impair processing, suggesting that the two types of information are processed in parallel (Peterson & Gibson, 1994). Determining whether infants demonstrate similar performance differences would lead to a more complete understanding of the development of figure/ground processing.

Moreover, the finding that infants as young as 5 months of age utilize learned top-down information to process figure/ground information is consistent with other reports of learning influencing perceptual organization in infancy (e.g., Bhatt & Quinn, 2011; Needham, 2016). For example, Quinn, Bhatt, Brush, Grimes, and Sharpnack (2002) found that 3.5-month-olds do not readily utilize shape similarity to group arrays; however, after experience with a variety of shape contrasts, they begin to organize arrays on the basis of shape similarity (Quinn & Bhatt, 2005). Thus, learning significantly affects perceptual organization in infancy. The current study adds to this literature by demonstrating that acquired information affects a particular kind of perceptual organization, namely figure/ground segregation, early in life.

The interpretation of the results of this study assumes that infants' figure/ground distinctions were stable through the entire test and that the preference displayed in the experimental condition was due to the familiar side of the ambiguous image being permanently designated as the "figure." However, it is possible that infants' figure/ground distinctions were more dynamic and reversed throughout the test and the observed preference was due to the familiar side being designated as "figure" longer than the opposing side. Regardless of whether infants figure/ground distinctions were dynamic or static, the present study demonstrates object recognition impacts figure/ground processing in infancy. Additional work is needed to determine the stability of this process.

In conclusion, the current study demonstrates that top-down processing, namely object recognition, systematically impacts figure/ground segregation in infancy. While many questions remain, this is an important step forward in understanding how the critical ability of figure/ground parsing is present and functional in early infancy.

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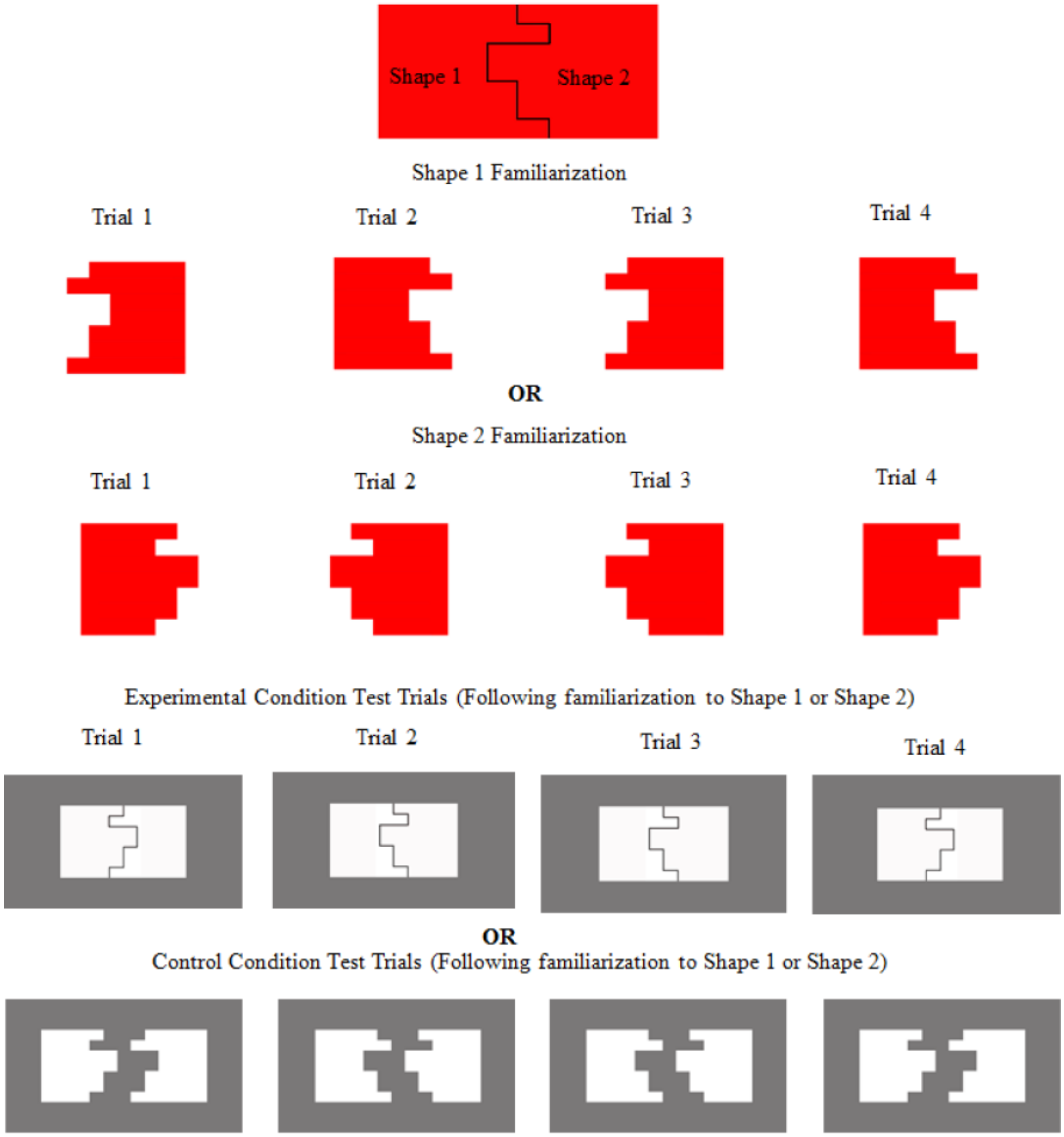

Figure 1.

Sample shapes, familiarization images, and test images. Each infant was only familiarized to one shape (Shape 1 or Shape 2, counterbalanced across infants). After familiarization, infants were tested on one set of test trials (ambiguous or control). For data collection purposes, AOIs were drawn around the white areas on both sides of the unique contour (not visible to the infants). If an infant was familiarized to Shape 1, the white area corresponding to Shape 1 was identified as the “figure” for coding purposes while the white area corresponding to Shape 2 was the “ground.” The designation was reversed for infants who were familiarized to Shape 2. Thus, across infants, each side of the ambiguous test stimulus was equally often the figure and background stimulus.

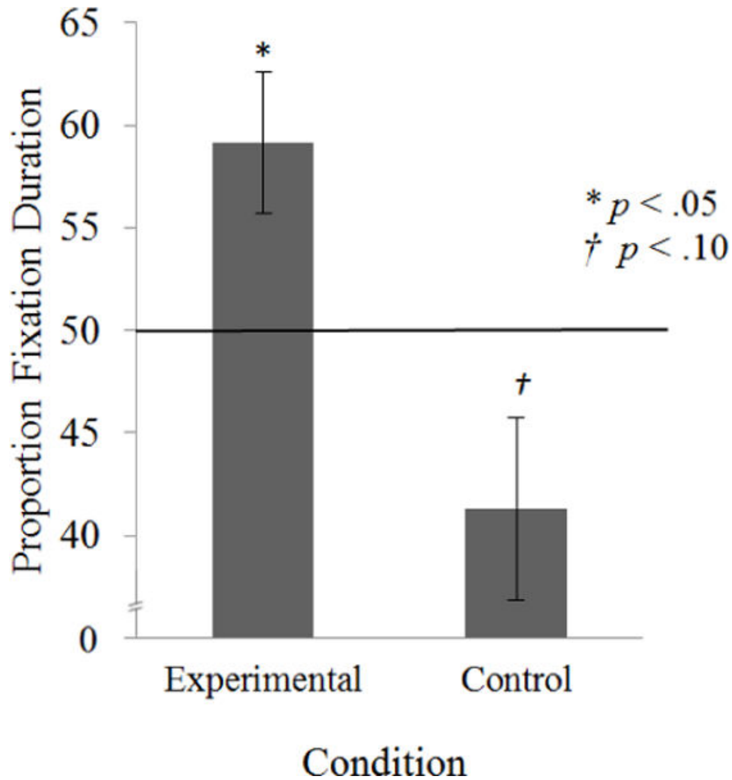

Figure 2.
Average proportion fixation durations toward the familiar shape for infants in the experimental ambiguous and control two-shape conditions. The significance levels are two-tailed values based on t-tests comparing the score in each condition to chance (50%).