The role of shape recognition in figure/ground perception in infancy

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Abstract

In this study we 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 were viewing 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 indicated that the results in the experimental condition were not due to a 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. In the present study we 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 (Biederman, 1987; Marr, 1982). This means that the predominant factors contributing to figure/ground 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 nonfamiliar shape. Such findings of shape recognition influencing figure/ground parsing have been replicated many times (Navon, 2011; Peterson & Gibson, 1994; Peterson, Harvey, & Weidenbacher, 1991; for a review, see Peterson, 1994). Thus, adults clearly utilize shape recognition during figure/ground parsing; however, it is unclear whether 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

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figure/ground perception by infants. One study showed that, similar 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 either 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' figure/ground perception can be systematically impacted by nonkinetic 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 do 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 on the basis of 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, & Umiltà, 2005; Nelson & Palmer, 2007; Zhang & Sclaroff, 2013). Therefore, if infants utilize previous knowledge in order 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 present 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 either the figure or the ground, but only one matched the familiarization image (Fig. 1). If infants attended more to the side of the image matching the familiarization image, this would be evidence that infants apply previous experience when making figure/ground distinctions in ambiguous stimuli. Such a finding would be indicative of an adult-like top-down influence on figure/ground perception early in life.

However, infants might not perceive the ambiguous image as a figure that matched the familiar shape surrounded by a shapeless ground. Instead, although 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-shaped side because of a familiarity preference. Although infants normally exhibit a novelty preference after a familiarization procedure of the sort used in the present study, they sometimes exhibit a familiarity preference (Galati, Hock, & Bhatt, 2016; Johnson et al., 2009). Therefore, infants' performance might have been due to a familiarity preference between shapes. To address this possibility, infants in a control group were shown test stimuli that clearly included two figures instead of an ambiguous shape. Specifically, the infants in this

condition were familiarized to shapes in exactly the same manner as the infants in the experimental condition, but they were tested with two explicit shapes: one that matched the familiar shape and another that matched the opposite side of the ambiguous image (Fig. 1). If infants' performance in the experimental condition were due to a familiarity preference, the infants in the control condition should behave similarly. If, however, there were differences in performance between the experimental and control conditions, this would suggest that infants were treating the ambiguous stimulus as if it had only one figure, and that their previous experience had 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; nine male, seven female) and 16 in the control/two-shape condition (mean age = 151.06 days, SD = 5.95; ten male, six female), were included in the final sample. The data from additional participants were excluded because they looked 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, 2007; 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 1.5 times the interquartile range beyond either the 1st or the 3rd quartile (n = 2). Participants were recruited via birth announcements and a local hospital, and they 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 in order to generate two shapes (Fig. 1). Notice that the shapes differ in their parts but share a 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, which were created by placing the unique contour (shared by the shapes) in a white box on a gray background (Fig. 1). In the ambiguous images, the white space on either side of the contour can be seen as either the figure or the ground. Because the test images were the same for both corresponding shapes, preferential looking to one side of the contour

Fig. 1 Sample shapes, familiarization images, and test images. Each infant was familiarized only with one shape (Shape 1 or Shape 2, counterbalanced across infants). After familiarization, the infants were tested on one set of test trials (ambiguous or control). For data collection purposes, areas of interest 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, and the white area corresponding to Shape 2 was the “ground.” These designations were 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 the background stimulus

could not be attributed to low-level features (e.g., protrusions). 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 could not be attributed to idiosyncratic features of one side. Two sets of familiarization and test images were created using this method. Additionally, to prevent biases to look at a single side from skewing performance, all of the images were flipped about the horizontal axis, to make a total of eight familiarization shapes and four test images. The 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 the right side of the shape equally often. On average, the stimuli subtended a horizontal and vertical visual angle of 23.24° and 13.60°, respectively.

Control two-shape condition The familiarization stimuli were the same as in the ambiguous condition. The test stimuli were created by separating the white shapes (Fig. 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. The parents wore opaque glasses and were instructed not to direct their infant's looking in any way. Each infant experienced four 15-s familiarization trials (one shape in two orientations, Fig. 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, Fig. 1). Preceding each trial, an attention getter (alternating shapes) appeared at the center of the screen. When the infant had 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 Fig. 1 for an example). Thus, the left (L)–right (R) pattern for half of the infants was (LRLLRRL), and for the other half it was (RLLRLLR). The left/right locations for the first familiarization trial and the first test trial were counterbalanced across infants and shapes.

A Tobii TX300 eyetracker 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 the 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 60 ms 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, Quinn, Pascalis, & Lee, 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. The AOIs were identical in size. Depending on the familiarization shape that a given infant had seen, the AOI covering the side of the image that matched the familiarization shape was designated the “figure,” and the other was the “ground.” In the control two-shape condition, the 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 the 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 the infants in the experimental condition, but not in the control condition, would attend more to the side of the contour they perceive as the figure, resulting in a preference score that would be significantly greater than 50% chance.

Results

The average accumulated fixation durations during familiarization did not differ systematically between the experimental ($M = 28.73$ s, $SD = 2.61$) and control ($M = 31.21$ s, $SD = 2.65$) 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”; Fig. 2). An independent-samples t test comparing the proportion fixation durations 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 durations of the infants in the ambiguous condition to chance (50%) found that these 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, the infants in the two-shape condition displayed a proportion

Fig. 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%)

fixation duration to the “figure” AOI that did not differ from chance, $t(15) = -1.96$, $p = .07$, $d = 0.49$. Thus, the infants in the control condition exhibited a nonsignificant 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 they are presented with ambiguous displays, and that such performance is not driven by a simple familiarity preference between two different shapes.

However, as was pointed out by a reviewer, it is possible that the 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, in which the stimuli were more clearly defined. Although 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 et al., 2005; Nelson & Palmer, 2007; Zhang & Sclaroff, 2013). If the infants in the experimental condition were interpreting the ambiguous display as containing only one figure, their preference for the figure over the ground would be expected to 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 (nonsignificant) novelty preference between two figures in the control condition, then there would be no expectation of differences in the magnitudes of the 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 fixations over all trials to the “ground.” An independent-samples t test demonstrated that the infants in the experimental condition showed significantly greater difference scores ($M = 3.52$; $SE = 0.62$) than did the infants in the control condition ($M = 1.53$, $SE = 0.35$), $t(30) = 2.80$, $p = .009$, $d = 0.99$. Thus, the 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 the infants in the control condition were treating both shapes as figures, resulting in more competition for attention, whereas the infants in the experimental condition were interpreting one side of the ambiguous image as the figure. The difference score analysis therefore supports the interpretation that the infants in the experimental condition were responding to a figure–ground contrast, whereas those in the control condition were responding to a figure–figure contrast.

Discussion

In the present study we 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 at the side that matched this stimulus than at the opposite side, even though each side could be either the figure or the ground. This finding indicates that infants segregated the figure from the ground on the basis of prior experience with one of the possible images. Moreover, a familiarity preference between the 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 and 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 we previously mentioned, research on figure/ground processing in infancy has shown that kinetic cues (Arterberry et al., 1993; 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 et al., 2009) suggest that infants segregate figure from ground with low-level stimulus cues. The finding in the present study that infants as young as 5 months utilized 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, and 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 present 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 that they reversed throughout the test, so that the observed preference was due to the familiar side being designated as "figure" for longer than the opposing side. Regardless of whether infants' figure/ground distinctions were dynamic or static, the present study demonstrates that object recognition impacts figure/ground processing in infancy. Additional work will be needed to determine the stability of this process.

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

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