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Size and orientation cue figure-ground segregation in infants

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Abstract

Adult perceivers segregate figure from ground based on image cues such as small size and main axis orientation. The current study examined whether infants can use such cues to perceive figure-ground segregation. Three- to 7-month-olds were familiarized with a pie-shaped stimulus in which some pieces formed a + and other pieces formed an x. The infants were then presented with a novelty preference test pairing the + and x. The bases for the pieces forming the + or x were size and orientation (Experiment 1), size (Experiment 2), and orientation (Experiment 3). In each experiment, infants responded as if they recognized as familiar the shape specified by small size, main axis orientation, or their combination. Control conditions showed that infant performance could not be attributed to spontaneous preference. The findings suggest that infants can achieve figure-ground segregation based on some of the same cues used by adults.

Keywords

Figure-ground segregation; infant perception; perceptual organization

Evidence suggests that the development of perceptual organization is guided during infancy by adherence to principles that specify how small elements should be grouped to form larger perceptual wholes (Bhatt & Quinn, 2011). These principles include common motion (Johnson & Aslin, 1996; Kellman & Spelke, 1983), common region (Bhatt, Hayden, & Quinn, 2007), connectedness (Hayden, Bhatt, & Quinn, 2006), form similarity (Quinn, Bhatt, Brush, Grimes, & Sharpnack, 2002), good continuation (Quinn & Bhatt, 2005a), lightness similarity (Quinn, Burke, & Rush, 1993), and proximity (Quinn, Bhatt, & Hayden, 2008). Although the operation of some principles such as lightness similarity or proximity may be functional at birth (Farroni, Valenza, Simion, & Umiltà, 2000), the activation of other principles such as form similarity may be facilitated through experience or via bootstrapping onto already functioning principles. For example, supporting a role for experience, 3- to 4-month-olds do not show sensitivity to form similarity when presented with alternating columns or rows of a particular form contrast (i.e., X- O, H-I, or square-diamond), but do show such sensitivity when they concurrently experience all three form

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contrasts depicting a common organization (Quinn & Bhatt, 2005b). Likewise, consistent with a role for bootstrapping, 3- to 4-month-olds who do not show sensitivity to form similarity when presented with alternating columns or rows of a particular form contrast (i.e., X-O) will show such sensitivity when first presented with alternating columns or rows of a specific lightness contrast (i.e., light and dark squares) (Quinn & Bhatt, 2009). This latter finding suggests a scaffolding from a functioning principle (lightness similarity) to one not yet fully operational (form similarity). Collectively, the findings point toward a hybrid model of the development of perceptual organization incorporating inherent grouping principles as well as a role for learning from a structured environment (Quinn & Bhatt, 2015; Spelke, 1982).

Compared to the development of perceptual grouping, much less is known about the development of figure-ground segregation. This is somewhat surprising given that to advance cognitively, infants will need to segregate the environment into defined shapes that stand out against an undifferentiated background. Moreover, investigations of mature visual perception have turned up a number of cues that adults use to achieve figure-ground segregation, including orientation, size, symmetry, convexity, and surroundedness. Regions of stimuli that are smaller, symmetrical, convex, enclosed, and located along the main axes (i.e., horizontal or vertical) are more likely to be perceived as figure (e.g., Driver, Baylis, & Rafal, 1992; Harrower, 1936; Palmer, 1999; Peterson & Salvagio, 2008; Rock, 1983; Rubin, 1958; Wagemans et al., 2012). Although there is evidence that infants are sensitive to a number of these properties (e.g., orientation: Quinn & Bhatt, 1998; symmetry: Bornstein & Krinsky, 1985; Guy, Reynolds, Mosteller & Dixon, 2017; convexity: Bhatt, Hayden, Reed, Bertin, & Joseph, 2006; enclosed region: Bhatt et al., 2007), few published studies have directly investigated figure-ground segregation by infants or examined the stimulus properties that might serve as cues to figure-ground segregation in infants.

To our knowledge, only three published studies have specifically examined figure-ground perception in infants. In one of those investigations, Takashima, Kanazawa, Yamaguchi, and Shiina (2014) familiarized 7- to 8-month-old infants with a Rubin goblet stimulus in which the vase was the figure. The infants were then preference tested with stimuli in which either the vase was the figure or the two faces were the figure. Although the infants preferred the novel figure when the background of the familiarization stimulus was homogeneous (i.e., a consistent shade of gray) they did not prefer the novel figure when the background of the familiarization stimulus was heterogeneous (i.e., two different shades of gray). Thus, decreased homogeneity of the background impaired the ability of 7- to 8-month-olds to achieve figure-ground segregation, just as it does in adults (Peterson & Salvagio, 2008).

In another study investigating figure-ground segregation by infants, Ross-Sheehy, Perone, Vecera, and Oakes (2016) presented 6.5-month-old infants with pairs of stimuli in which the individual stimuli within a pair consisted of bordering symmetrical and asymmetrical images. One of the images moved relative to the other image in a way that was consistent or inconsistent with figure-ground perception (e.g., the symmetrical region moved in front of the asymmetrical region or the asymmetrical region moved in front of the symmetrical region). The key finding was that sitting infants at 6.5 months (i.e., infants who could sit unassisted), but not non-sitting infants at the same age, displayed a visual preference for the

consistent stimuli, suggesting that they were sensitive to symmetry as a cue to figure-ground segregation. Given that symmetry reflects an environmental regularity, the findings were interpreted as evidence that motor development may contribute to the detection of this regularity, possibly by creating experiential opportunities for learning the regularity. This interpretation is in accord with the structuralist position that experience is an important determinant of figure-ground organization (i.e., perception of objects in a given scene is based on past experience with those objects; see, for example, discussion in Peterson, 2015).

More recently, White, Jubran, Heck, Chroust, and Bhatt (2018) found that immediate experience directly affects figure-ground segregation in a top-down manner in infancy. After familiarization to a shape, 5-month-olds in that study 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. Thus, experience with shapes affected subsequent figure-ground segregation at 5 months, just as familiarity has been shown to affect figure-ground segregation in adults (Peterson & Gibson, 1994).

While the use of symmetry, recently experienced shapes, and other cues to figure-ground segregation such as lower region (Vecera & Palmer, 2006) may depend on experience, the ability to use at least some image-based cues may be present from early in development. Such findings would be consistent with the Gestalt perspective that “the articulation of our field ... into figures and ground ... appears ... as the direct result of the stimulus distribution, i.e., as the spontaneous organization aroused by the stimulus mosaic” (Koffka, 1935, p. 209). We therefore undertook an investigation to determine whether infants as young as 3 to 4 months of age would use orientation and size information as cues to figure-ground segregation. We chose to study orientation and size information as cues because (as noted) there is evidence that adults use these cues to achieve figure-ground segregation, with horizontal/vertical orientations and small size inducing figure perception (Oyama, 1960; Rubin, 1958). Why the horizontal/vertical and small values along the orientation and size attributes are perceived as figure is unknown, although horizontal and vertical tend to be perceived as unique categories along the orientation continuum (Quinn, 2004), and small-sized stimuli tend to be perceived as distinctive (Coren, Porac, & Ward, 1984) and require less processing time (Kanai, Dalmaijer, Sherman, Kawakita, & Paffen, 2017). In addition, there are data indicating that infants are sensitive to differences between horizontal/vertical and oblique orientations (Quinn & Bomba, 1986) and also to differences in object size (Libertus et al., 2013). Finally, the differences in orientation and size were marked by differences in luminance, a further attribute to which infants have been shown to be sensitive (Quinn et al., 1993) and one that provides another basis by which figure-ground segregation can be achieved by adults (Kelly & Grossberg, 2000; Regan & Beverley, 1984).

Experiment 1

In Experiment 1, two different age groups of infants, 3- to 4-month-olds and 6- to 7-month-olds, were presented with an experimental condition that involved familiarization with the unfilled pie-shaped stimulus shown in the left panel of Figure 1. In this stimulus, the smaller pieces forming a + are more readily perceived by adults as figure based on the cues of small size and main axis orientation (Koffka, 1935; Kunnappas, 1957; Oyama, 1960; Rubin, 1958),

with the larger pieces forming an x viewed as ground. The infants were then preference tested with the pie-shaped stimulus in which the horizontal-vertical regions were filled to form the + paired with the pie-shaped stimulus in which the diagonal regions were filled to form the x. If the infants perceive the pieces forming the + in the familiarization stimulus as figure based on small size, main axis orientation, or their combination, then they should recognize the filled + and prefer the filled x during the test. This reasoning is based on the expectation of a novelty preference (Fantz, 1964) and evidence that both adults (Palmer, 1999; Rock, 1983; Rubin, 1958) and infants (Hayden, Bhatt, Kangas, & Zieber, 2011) are more likely to remember aspects of stimuli that are perceived as figure relative to aspects of stimuli that are perceived as ground.

To discount a possible role for spontaneous preference for the filled x over the filled +, same-aged infants in a control group were preference tested with the pie-shaped stimulus with the filled + paired with the pie-shaped stimulus with the filled x, but without first being presented with the unfilled pie shape as a familiarization stimulus. A direct statistical comparison between the performance of the experimental and control groups can then be used to determine if the performance of the experimental group was due to the processing of the familiarization stimulus (Oakes, 2010). The inclusion of the 3- to 4-month-olds in the experimental design allows for investigation of figure-ground segregation in an age group that is not yet sitting and is 2–3 months younger than the youngest age group previously studied in connection with figure-ground segregation (Ross-Sheehy et al., 2016; Takashima et al., 2014; White et al., 2018).

Method

Participants—Participants were 64 infants, 32 3- to 4-month-olds (17 females), mean age = 113.38 days, SD = 14.34 days, and 32 6- to 7-month-olds (17 females), mean age = 193.78 days, SD = 15.02 days. Four additional infants were tested, but three did not complete the procedure due to fussiness, and one was excluded from the data analysis because of failure to compare the test stimuli.

Stimuli—The stimuli (shown in Figure 1) were spheres cut into pie pieces or propeller blades. The sphere was 12.9 cm in diameter and its outer circumference was .2 cm in thickness. In the familiarization stimulus, the propeller blades along the horizontal and vertical axes were smaller than the propeller blades along the diagonal axes. In one test stimulus, the small main-axis propeller blades were filled (i.e., shaded), and in the other test stimulus, the large diagonal propeller blades were filled. The propeller blades forming the large regions gave rise to an angle of 55° from the centre of the sphere, and the propeller blades forming the small regions gave rise to an angle of 35° from the centre of the sphere.

Apparatus—Infants were tested in a visual preference apparatus, modelled after that of Fagan (1970). The apparatus has a gray display panel that includes two compartments to hold the stimuli. The stimuli were illuminated by a fluorescent lamp that was shielded from the infant's view. Center-to-center distance between compartments was 30.5 cm and on all trials the display panel was situated approximately 30.5 cm in front of the infant. There was a 0.62 cm peephole located midway between the compartments that permitted an observer to

record infant visual fixations. A second peephole, 0.90 cm in diameter, located directly below the first peephole, permitted a Pro Video CVC-120PH pinhole camera and Magnavox DVD recorder to record infant gaze duration.

Procedure—Infants were tested individually and brought to the laboratory by a parent. Each infant was first seated in a reclining position on the parent's lap. An experimenter then moved the apparatus into position over the infant, keeping the infant's head centred with respect to the midline of the display stage. To begin a trial, the experimenter would load the stimuli into the compartments on the display stage, elicit the attention of the infant, and close the stage, thereby exposing the stimuli to the infant. When the stage was closed, it was positioned approximately 30 cm above and in front of the infant, and the infant could see only the two stimuli and the gray surround of the viewing chamber. During a trial, the experimenter observed the infant through the upper peephole and recorded fixations to the left and right stimuli with a 605 XE Accusplit stopwatch (Pleasanton, CA, USA) held in each hand. The criterion for fixation was observing corneal reflection of the stimulus over the infant's pupil. Between trials, the experimenter opened the stage, recorded the looking time data, re-centered the infant's gaze, and closed the stage. For the experimental groups, two experimenters were used to record fixations, one during familiarization and another during test trials. Both experimenters were naive to the hypotheses under investigation. The test for the infants in the control condition required only a single experimenter to record fixations who was also naive to the hypotheses being investigated. The experimenter recording during the two preference test trials of the experimental and control groups was kept away from the experimental room until the point at which the trials were to begin (i.e., the test stimuli were positioned in the apparatus, and the infant was ready for them to be presented). This experimenter was thus kept naive to the testing condition (experimental vs. control) of a particular infant.

Infants from each of the two age groups were randomly divided into an experimental group and a control group with 16 infants in each. The experimental group was presented with two identical copies of the familiarization stimulus shown in Figure 1 on four 15-s familiarization trials. Immediately after familiarization, each infant received two 10-s novelty preference test trials, pairing the test stimuli shown in Figure 1. Within the experimental group, the left-right positioning of the two stimuli was counterbalanced across infants on the first test trial and reversed on the second test trial. The control group was not presented with a familiarization stimulus; the infants from this group only took part in the two preference test trials that were administered in the same manner described for the experimental group. Inter-observer agreement, as determined by comparing looking times measured by the experimenter using the centre peephole, and an additional naive observer measuring looking times offline from DVD records, was calculated for the test trials of 16 infants (4 from each combination of age [3- to 4-month-olds vs. 6- to 7-month-olds] and group [experimental vs. control]). Average level of agreement was 98.06% ($SD=1.54$). In addition, the average of the difference scores for the original and reliability-check novel category preference scores was -0.10 , $SD=1.21$, which was not significantly different from 0, $t(15) = -0.33$, $p = .746$, indicating that the differences between observers were randomly

distributed, rather than having one observer with consistently higher or lower scores relative to the other observer.

Results and discussion

Familiarization trials—Individual looking times were summed over the left and right copies of the stimulus presented on each trial to the experimental group and then averaged across the first two and last two trials. Mean looking times are shown in Table 1. An analysis of variance (ANOVA), Age (3- to 4-month-olds vs. 6- to 7-month-olds) x Trials (1–2 vs. 3–4), performed on the individual scores, revealed only a significant a main effect of Trials, $F(1, 30) = 9.57$, $p = .004$, partial $\eta^2 = .24$. The significant effect of Trials indicates that both age groups displayed a reliable decrement in looking time, indicating habituation (Cohen & Gelber, 1975).

Preference test trials—Each infant's looking time to the presumed novel stimulus, the x (based on the assumption that the smaller and horizontal-vertical propeller blades would be perceived as figure and hence more likely to be represented in memory), was divided by the looking time to both test stimuli and converted to a percentage score. Mean novelty preference scores are shown in Table 1. An ANOVA performed on the individual preference scores, with factors of Group (experimental vs. control) and Age (3- to 4-month-olds vs. 6- to 7- month-olds), yielded only an effect of Group, $F(1, 60) = 7.57$, $p = .007$, partial $\eta^2 = .11$, indicating that the experimental group infants displayed higher preference scores than the control group infants. The Group effect supports the argument that the performance of the experimental group reflected their processing of the figure-ground relations in the familiarization stimulus. Evidence further supporting this argument comes from the comparisons of the mean preferences to the chance value of 50%, which revealed that only the experimental group infants looked reliably longer to the novel than to the familiar stimulus (Table 1). The pattern of performance of individual infants relative to chance paralleled those observed at the group level: whereas 24 (11 3- to 4-month-olds and 13 6- to 7-month-olds) of 32 infants in the experimental group displayed individual preference scores greater than 50% (binomial probability = .007), just 13 (6 3- to 4- month-olds and 7 6- to 7-month-olds) of 32 infants in the control group displayed individual preference scores greater than 50% (binomial probability = .38). The scattering of the differences in performance is further depicted in Figure 2, where the individual preference scores for the infants in the experimental and control groups are plotted. The pattern of both the mean and individual preference scores suggests that infants had achieved figure-ground segregation based on the cues of size, orientation, or their combination.

Experiment 2

Although Experiment 1 demonstrated that infants could segregate figure from ground, the segregation could have been driven by a single cue (either size or orientation) or multiple cues in combination (size and orientation). Experiment 2 was designed both to (1) provide convergent evidence with Experiment 1 that infants can achieve figure-ground segregation even with relatively ambiguous stimuli of the sort used in these experiments, and (2) be more specific about the cues that were driving the segregation. In particular, Experiment 2

sought to uncouple the cue of small size from main axis orientation, and determine whether infants could separate figure from ground based on the cue of small size. As in Experiment 1, two different age groups of infants, 3- to 4-month-olds and 6- to 7-month-olds, were presented with an experimental condition that involved familiarization with the unfilled pie-shaped stimulus shown in the left panel of Figure 3. In this instance, the smaller pieces forming the x are more readily perceived by adults as figure, with the larger pieces forming the + viewed as ground (Koffka, 1935; Kunnapas, 1957; Oyama, 1960; Rubin, 1958). The infants were then preference tested with a pie-shaped stimulus in which the pieces forming the x were filled paired with a pie-shaped stimulus in which the pieces forming the + were filled. Following the logic of Experiment 1, if the infants were more likely to perceive the pieces forming the x in the familiarization stimulus as figure, then they should recognize the filled x and prefer the filled + during the test. To discount a possible role for spontaneous preference for the filled + over the filled x, same-aged infants in a control group were preference tested with the pie-shaped stimulus with the filled x paired with pie-shaped stimulus with the filled +, but without first being presented with the unfilled pie shape as a familiarization stimulus.

Method

Participants—Participants were 64 infants, 32 3- to 4-month-olds (14 females), mean age = 113.69 days, SD = 11.89 days, and 32 6- to 7-month-olds (15 females), mean age = 195.28 days, SD = 16.08 days. Six additional infants were tested, but four did not complete the procedure due to fussiness, and two were excluded from the data analysis because of failure to compare the test stimuli.

Stimuli—The stimuli (shown in Figure 3) had the same dimensions as those used in Experiment 1, except that the propeller blades along the horizontal and vertical axes were larger than the propeller blades along the oblique axes. In one test stimulus, the small diagonal propeller blades were filled (i.e., shaded), and in the other test stimulus, the large main-axis propeller blades were filled.

Procedure—The procedure was the same as in Experiment 1. Interobserver agreement was calculated for the test trials of 16 infants (4 from each combination of age [3- to 4-month-olds vs. 6- to 7-month-olds] and group [experimental vs. control]). Average level of agreement was 97.46% (SD = 2.70). In addition, the average of the difference scores for the original and reliability-check novel category preference scores was -0.15 , SD = 1.85, which was not significantly different from 0, $t(15) = -0.32$, $p = .753$, indicating that the differences between observers were randomly distributed.

Results and discussion

Familiarization trials—Mean looking times for the experimental group on Trials 1–2 and Trials 3–4 are presented in Table 2. An ANOVA, Age (3- to 4-month-olds vs. 6- to 7-month-olds) $\times$ Trials (1–2 vs. 3–4), performed on the individual scores, revealed a significant main effect of Trials, $F(1,30) = 12.17$, $p = .001$, partial $\eta^2 = .29$, and a marginally reliable effect of age, $F(1, 30) = 3.65$, $p = .062$, partial $\eta^2 = .11$. The significant effect of Trials indicates that both the 3- to 4-month-olds and 6- to 7-month-olds showed a reliable decrease in

looking time that is in keeping with habituation. The marginal effect of Age indicates that there was a trend for the younger infants to look more at the stimuli than the older infants did, an effect that has sometimes been observed with infants in the same age range presented with visual pattern stimuli (e.g., Courage, Reynolds, & Richards, 2006; Quinn et al., 2002).

Preference test trials—Individual novelty preference scores were in this instance computed as a preference for the +, the presumed novel stimulus if infants were perceiving the x as familiar. Mean novelty preference scores for the experimental and control groups at each age are shown in Table 2. An ANOVA performed on the individual preference scores, with factors of Group (experimental vs. control) and Age (3- to 4-month-olds vs. 6- to 7-month-olds), yielded only an effect of Group, $F(1, 60) = 4.79$, $p = .03$, partial $\eta^2 = .07$, indicating that the experimental group infants displayed higher preference scores than the control group infants. In addition, comparisons of the mean preferences to the chance value of 50% revealed that only the experimental group infants looked reliably longer to the novel than to the familiar stimulus (Table 2). The pattern of performance of individual infants relative to chance resembled that observed at the group level: 23 (11 3- to 4-month-olds and 12 6- to 7-month-olds) of 32 infants in the experimental group displayed individual preference scores greater than 50% (binomial probability = .02), whereas 18 (8 3- to 4-month-olds and 10 6- to 7-month-olds) of 32 infants in the control group displayed individual preference scores greater than 50% (binomial probability = .60). Figure 4 plots the individual preference scores for the infants in the experimental and control groups and illustrates the distribution of the differences in performance. Both the mean and individual preferences converge to suggest that infants had separated figure from ground based on the cue of small size.

Experiment 3

Although the results of the first two experiments are consistent with the segregation of figure from ground by infants, there is an alternative explanation of performance. Specifically, infants in the preference test trials of the experimental conditions could have looked longer at the test stimulus that is more different from the familiarization stimulus in terms of amount of blackness. By this account, infants are not engaging in figure-ground segregation, but merely preferring the test stimulus that is more dissimilar to the familiarization stimulus in amount of blackness.

Experiment 3 was conducted to choose between these alternatives and to examine whether infants are sensitive to orientation as a cue for figure-ground segregation. Three- to 4-month-olds and 6- to 7-month-olds were familiarized with the unfilled pie shape shown in Figure 5. This stimulus matches the familiarization stimuli used in Experiments 1 and 2 in terms of the amount of blackness and the presence of lines, but is composed of equally sized regions. The infants were then assessed for their preference between the test stimuli from Experiment 2, a pie-shaped stimulus in which the smaller pieces forming the x were filled paired with a pie-shaped stimulus in which the larger pieces forming the + were filled. If the infants in the previous experiments were simply responding preferentially to the test stimulus with more darkness relative to the familiarization stimulus, then they should prefer the pie-shaped stimulus with larger filled regions forming the +. However, if the infants in the prior

experiments were engaging in figure-ground segregation, then we would not expect a preference for one test stimulus over the other, given the null results of the control group from Experiment 2 and the consideration that neither test stimulus is an exact match for the presumed figure in the familiarization stimulus (i.e., the +). It is also possible that the infants in the current experiment could show a preference for the pie-shaped stimulus with smaller filled regions forming the x. This latter result would suggest that infants perceived the pieces forming the + in the familiarization stimulus as figure, and then generalized to the filled + at test (despite the difference in size). Such an outcome would be consistent with infant use of main-axis orientation to segregate figure from ground, a cue which adults have been shown to use for figure-ground segregation (Koffka, 1935; Kunnapas, 1957; Oyama, 1960; Rubin, 1958).

Method

Participants—Participants were 32 infants, 16 3- to 4-month-olds (7 females), mean age = 109.63 days, $SD = 12.43$ days, and 16 6- to 7-month-olds (6 females), mean age = 198.00 days, $SD = 11.80$ days. Two additional infants were tested but did not complete the procedure due to fussiness.

Stimuli—The familiarization stimuli (shown in Figure 5) had the same dimensions as those used in Experiments 1 and 2, except that the propeller blades along the horizontal, vertical, and oblique axes were all the same size. The test stimuli were the same as those used in Experiment 2.

Procedure—The procedure was the same as in Experiments 1 and 2, except that there was no new control group (given that the test stimuli in Experiment 3 were those presented in Experiment 2). Inter-observer agreement was calculated for the test trials of 8 infants (4 from each age: 3- to 4-month-olds vs. 6- to 7-month-olds). Average level of agreement was 98.45% ($SD = 1.32$). In addition, the average of the difference scores for the original and reliability-check novel category preference scores was -0.13 , $SD = 0.99$, which was not significantly different from 0, $t(7) = -0.22$, $p = .832$, indicating that the differences between observers were randomly distributed.

Results and discussion

Familiarization trials—Mean looking times on Trials 1–2 and Trials 3–4 are presented in Table 3. An ANOVA, Age (3- to 4-month-olds vs. 6- to 7-month-olds) $\times$ Trials (1–2 vs. 3–4), performed on the individual scores, revealed significant a main effect of Trials, $F(1, 30) = 7.31$, $p = .011$, partial $\eta^2 = .20$, and a reliable effect of age, $F(1,30) = 6.16$, $p = .019$, partial $\eta^2 = .17$. Consistent with habituation, both age groups exhibited a reliable decrement in looking time from the first to the second half of familiarization. The Age effect indicates that the 3- to 4-month-olds looked more at the stimuli than did the 6- to 7-month-olds, an effect which (as mentioned) has previously been reported for infants in this age range presented with visual patterns (e.g., Courage et al., 2006; Quinn et al., 2002).

Preference test trials—Individual novelty preference scores were in this instance computed as a preference for the x, the presumed novel stimulus if infants are perceiving the

+ as familiar. Mean novelty preference scores for the experimental group and control group (from Experiment 2) at each age are shown in Table 3. Given that the test stimuli were the same for Experiments 2 and 3, the control group scores for Experiment 3 were simple transforms ($100 - x$) of the control group scores from Experiment 2 (where the presumed novel stimulus for the experimental group was the +). An ANOVA performed on the individual preference scores, with factors of Group (experimental vs. control) and Age (3- to 4- month-olds vs. 6- to 7-month-olds), yielded only an effect of Group, $F(1, 60) = 8.10$, $p = .006$, partial $\eta^2 = .12$, indicating that the experimental group infants displayed higher preference scores than the control group infants. In addition, comparisons of the mean preferences to the chance value of 50% revealed that only the experimental group infants looked reliably longer to the novel than to the familiar stimulus (Table 3). The pattern of performance of individual infants relative to chance paralleled those observed at the group level: whereas 28 (13 3- to 4-month-olds and 15 6- to 7-month-olds) of 32 infants in the experimental group displayed individual preference scores greater than 50% (binomial probability = .00002), only 14 (8 3- to 4-month-olds and 6 6- to 7-month-olds) of 32 infants in the control group displayed individual preference scores greater than 50% (binomial probability = .60). The spread of differences in performance is further displayed in Figure 6, which shows the individual preference scores for infants in the experimental and control groups. Both the mean and individual preferences converge to suggest that infants had separated figure from ground based on the cue of orientation (i.e., horizontal and vertical main axes).

General discussion

The current investigation examined whether infants could use size, orientation, and their combination as cues to figure-ground organization in the developmental period between 3 and 7 months of age. In Experiment 1, infants in an experimental group who were familiarized with a pie-shaped stimulus with the smaller pieces forming a + and the larger pieces forming an x subsequently preferred the x over the +. The result suggests that the infants perceived the + as the figure in the familiarization stimulus, and recognized the + as more familiar when it was paired with the x at test. This interpretation is consistent with the finding that adults remember figures more strongly than grounds (Palmer, 1999; Rock, 1983; Rubin, 1958). The outcome from the control group supported this interpretation by demonstrating that the preference for the + did not reflect an a priori preference. Taken together, the findings provide the first evidence of which we are aware that infants as young as 3 to 4 months of age can use cues engaged by adults to segregate figure from ground.

One limit of interpreting the outcome of Experiment 1 is that because the smaller pieces of the familiarization stimulus formed main axis regions and the larger pieces formed oblique regions, infants could have used just a single cue (either size or orientation) or the combination of cues (size and orientation) as a basis for separating figure from ground. Experiment 2 was therefore designed to determine if infants could segregate figure from ground based on the single cue of size. Three- to 7-month-olds familiarized with a pie-shaped stimulus in which the smaller pieces formed the x and the larger pieces formed the + subsequently preferred the + over the x, a preference that was not observed in the control group assessing spontaneous preference. The results suggest that the infants perceived the x

as the figure during familiarization, and recognized it as more familiar at test when paired with the +. The findings from Experiment 2 indicate that infants can achieve figure-ground segregation based on the cue of small size, a cue that adults have been shown to use for separating figure from ground (Koffka, 1935; Kunnapas, 1957; Oyama, 1960; Rubin, 1958).

A potential limitation of the first two experiments is that infant performance could simply have been driven by a preference for the test stimulus that was more dissimilar to the familiarization stimulus in terms of amount of blackness. However, in Experiment 3, infants familiarized with a pie shape consisting of equally sized regions subsequently preferred the x over the +. Notably, the x and the + used in the preference test of Experiment 3 were the same stimuli used in the preference test of Experiment 2. The reversal in preference from Experiment 2 to Experiment 3 thus weakens the explanation that infant performance in the first two experiments reflected a novelty response to a dissimilar amount of blackness. Moreover, the findings from Experiment 3 indicate that infants, like adults (Koffka, 1935; Kunnapas, 1957; Oyama, 1960; Rubin, 1958), can use main-axis orientation information to segregate figure from ground.

While the present work utilized a traditional and reliable looking time measure of performance (Aslin, 2007; Fantz, 1964), it would be informative to learn if convergent evidence could be established for the conclusion that infants in the current experiments achieved figure-ground segregation. For example, given the arguments of Hebb (1949) that representations of visual images are constructed from the eye movements deployed by infants during scanning of those images, it may be that infant fixations of the familiarization stimuli would be concentrated on the portions of the stimuli perceived by adults to be the figural regions. Use of an eye-tracking procedure would thus provide a potentially enlightening supplement to the looking-time data reported here (Yeung, Denison, & Johnson, 2016).

As noted in the introduction, previous work on the development of perceptual organization in infants has concentrated on the principles by which infants group elements to form larger perceptual units or perceptual wholes (e.g., Bhatt & Quinn, 2011). That work has suggested that while some grouping principles may be operative from early in development, other principles may be later developing, and learned through experience with the structure of the environment or via bootstrapping onto already functional principles (Quinn & Bhatt, 2015; Spelke, 1982). When the currently reported data are considered in conjunction with the findings from the other infant studies on figure-ground perception (Ross-Sheehy et al., 2016; Takashima et al., 2014; White et al., 2018), the cues that infants use to achieve figure-ground segregation might reflect a similar dichotomy. That is, size and orientation may be early developing. Other candidates for additional early emerging cues would include the image based principles of convexity and surrounded-ness (Harrower, 1936; Palmer, 1999; Rock, 1983; Rubin, 1958; Wagemans et al., 2012). By contrast, in addition to symmetry (Ross-Sheehy et al., 2016), cues such as familiarity (Peterson & Gibson, 1994; White et al., 2018) and lower region (Vecera & Palmer, 2006) might be expected to be later developing, emerging through experience with a structured environment. Additional investigation, including work with infants younger than 3 months of age, will be needed to evaluate the

proposed developmental framework for the emergence of cues for figure- ground segregation.

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Figure 1.
The familiarization and test stimuli used to investigate figure-ground segregation in infants in Experiment 1.

Figure 2. Individual novelty preference scores (in percentages) plotted as a function of group (experimental versus control). Each filled circle represents the performance of an individual infant.

Figure 3.
The familiarization and test stimuli used to investigate figure-ground segregation in infants in Experiment 2.

Figure 4. Individual novelty preference scores (in percentages) plotted as a function of group (experimental versus control). Each filled circle represents the performance of an individual infant.

Figure 5.
The familiarization and test stimuli used to investigate figure-ground segregation in infants in Experiment 3

Figure 6. Individual novelty preference scores (in percentages) plotted as a function of group (experimental versus control). Each filled circle represents the performance of an individual infant.

Table 1.

Mean Fixation Times (seconds) During the Familiarization Trials and Mean Novelty Preference Scores (percentages) During the Preference Test Trials of Experiment 1

	Fixation Time				Novelty Preference		
	Trials 1–2		Trials 3–4				
	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>t^a</i>
<i>Experimental Groups</i>							
3- to 4-mth-olds	7.78	(3.50)	5.92	(3.26)	57.85%	(15.84)	1.98 [*]
6- to 7-mth-olds	6.19	(2.20)	5.11	(2.83)	59.61%	(12.46)	3.08 ^{****}
Combined					58.73%	(14.04)	3.52 ^{****}
<i>Control Groups</i>							
3- to 4-mth-olds					47.43%	(12.14)	−0.85
6- to 7-mth-olds					50.61%	(15.61)	0.16
Combined					49.02%	(13.85)	−0.40

^a t vs. chance.

* $p < .05$, one-tailed

**** $p < .01$.

Table 2.

Mean Fixation Times (seconds) During the Familiarization Trials and Mean Novelty Preference Scores (percentages) During the Preference Test Trials of Experiment 2

	Fixation Time				Novelty Preference		
	Trials 1–2		Trials 3–4				
	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>t^a</i>
<i>Experimental Groups</i>							
3- to 4-mth-olds	8.19	(3.79)	6.47	(3.96)	56.67%	(14.60)	1.83 [*]
6- to 7-mth-olds	6.13	(2.56)	4.50	(2.52)	60.40%	(15.37)	2.71 ^{***}
Combined					58.53%	(14.87)	3.24 ^{****}
<i>Control Groups</i>							
3- to 4-mth-olds					48.24%	(14.40)	−0.48
6- to 7-mth-olds					51.18%	(19.60)	0.24
Combined					49.71%	(16.98)	−0.10

^a t vs. chance.

* $p < .05$, one-tailed

*** $p < .02$

**** $p < .01$.

Table 3.

Mean Fixation Times (seconds) During the Familiarization Trials and Mean Novelty Preference Scores (percentages) During the Preference Test Trials of Experiment 3

	Fixation Time						<i>t</i> ^a
	Trials 1–2		Trials 3–4		Novelty Preference		
	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	
<i>Experimental Groups</i>							
3- to 4-mth-olds	8.27	(3.13)	5.61	(2.55)	59.91%	(15.57)	2.55**
6- to 7-mth-olds	5.88	(1.82)	4.86	(2.42)	62.75%	(11.37)	4.49*****
Combined					61.33%	(13.49)	4.75*****
<i>Control Groups</i>							
3- to 4-mth-olds					51.76%	(14.40)	0.48
6- to 7-mth-olds					48.82%	(19.60)	–0.24
Combined					50.29%	(16.98)	0.10

^a *t* vs. chance.
**
p < .05

p < .001.