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Spatial Resolution of Conscious Visual Perception in Infants

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Abstract

Humans' conscious awareness of objects in their visual periphery is limited. This limit is not entirely the result of reduced visual acuity. Rather, it is primarily caused by crowding—the difficulty identifying an object when it is surrounded by clutter. The effect of crowding on visual awareness in infants has yet to be explored. Do infants, for example, have a fine-grained "spotlight," as adults do, or do infants have a diffuse "lantern" that sets limits on what they can register in their visual periphery? We designed an eye-tracking paradigm to psychophysically measure crowding in infants between 6 months and 15 months of age. We showed infants pairs of faces at three eccentricities, in the presence or absence of flankers, and recorded infants' first saccade from central fixation to either face. Infants could discriminate faces in the periphery, and flankers impaired this ability. We found that the effective spatial resolution of infants' visual perception increased with age, but was only half that of adults.

Keywords

inversion, crowding, attention, peripheral vision, Mooney face

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In humans, conscious awareness of objects in the peripheral visual field is severely limited. This limitation is not entirely due to decreased visual acuity. The visual system is more fundamentally limited by crowding—the difficulty identifying individual objects that are surrounded by clutter (Levi, 2008; Pelli & Tillman, 2008). Phenomenologically, crowding causes an easily recognizable object in one's visual periphery to appear as a jumbled mass of unbound features (e.g., in Fig. 1, keeping one's gaze on the fixation cross, one can identify the letter *B* clearly when it is on its own, but not so clearly when it is surrounded by other letters). In other words, one can recognize that there is "stuff" in one's peripheral visual field, but one cannot identify a specific object within that clutter. Psychophysically measuring the effect of crowding in the peripheral visual field provides a means of estimating the size of the "spotlight," or window, that defines the spatial resolution of visual awareness. Crowding occurs whenever multiple objects fall within this window. This window has been well characterized in adults, but has not been studied in infants. However, understanding the spatial resolution of visual perception in infants is vital in order to understand the development of visual attention, object recognition, and visually guided action.

Although the spatial resolution of visual awareness has not been measured in infants, peripheral visual acuity has been tested in infants to a limited extent. Research with infants typically evaluates the direction and latency of a saccadic eye movement in response to the detection of a peripheral visual stimulus. Studies show that the visual field is quite narrow during the first months of life (approximately 30° of visual angle) and becomes progressively wider after 5 months (60°) and 1 year (80°–90°), slowly growing to the width of the adult visual field (de Schonen, McKenzie, Maury, & Bresson, 1978; Maurer & Lewis, 1979; Sireteanu, Fronius, & Constantinescu, 1994). Infants can also discriminate stimuli in their visual periphery on the basis of broad features such as size, color, and shape (Cohen, 1972; Maurer & Lewis, 1979; Salapatek, 1975), which suggests that they may have a more limited spotlight of visual awareness than adults, or perhaps a lantern rather than a spotlight of visual consciousness (Gopnik, 2009). The resolution of conscious peripheral vision in infants therefore remains an open question in the developmental field.

Measuring the effect of crowding on visual awareness offers a means of measuring the resolution of perception in the visual periphery. In adults, the crowding effect has been

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Fig. 1. An exercise to illustrate the effect of crowding on visual perception. In the top row, while one fixates on the cross, it is extremely difficult to identify the letter *B* in the middle of a string of letters that lie in the visual periphery. However, in the bottom row, while one fixates on the cross, it is easy to identify the letter *B* when it is presented in isolation in the visual periphery.

demonstrated with a range of stimuli, including gratings (Andriessen & Bouma, 1976), numbers (Strasburger, Harvey, & Rentschler, 1991), letters (Townsend, Taylor, & Brown, 1971), and faces (Farzin, Rivera, & Whitney, 2009; Louie, Bressler, & Whitney, 2007; Pelli, Palomares, & Majaj, 2004). In crowded scenes, the spatial resolution of perception is reduced proportionately to increased eccentricity and flanker density, such that an individual object is more difficult to identify when it is further away from fixation, and when flanking objects are closely spaced around it. Crowding usually occurs when the spacing between objects is less than half the eccentricity of the object in normal adult peripheral vision (Bouma's law), and does not occur in normal foveal vision (Bouma, 1970; Levi, 2008; Pelli & Tillman, 2008).

Experimental evidence strongly supports the theory that multiple mechanisms underlie the effects of crowding on adult visual perception, and that different levels of crowding can occur in adults. One model proposes that the inability to identify a crowded target item in one's visual periphery is the result of either interference between low-level elementary features within the same receptive field (Flom, Heath, & Takahashi, 1963; Kooi, Toet, Tripathy, & Levi, 1994) or excessive feature binding within an "integration field" (Pelli et al., 2004). Another model proposes that crowding is the result of a higher-level limit imposed on the resolution of spatial attention (He, Cavanagh, & Intriligator, 1997; Intriligator & Cavanagh, 2001). It is generally agreed upon, however, that crowding is the fundamental bottleneck to peripheral object recognition in natural scenes (Levi, 2008; Pelli & Tillman, 2008).

To quantify the resolution of peripheral vision in infants, we developed the first paradigm to psychophysically measure crowding in infants. Using Mooney faces (Mooney, 1957) as stimuli, we examined the ability of infants between the ages of 6 months and 15 months to discriminate face orientation (upright or inverted) at three different eccentricities in the visual periphery, in the presence or absence of surrounding flankers. The threshold eccentricities for discriminating uncrowded upright faces and crowded upright faces were calculated for each infant, to provide a measure of the crowding effect, which defines the spatial resolution of visual awareness.

Experiment 1

Method

Participants. One hundred sixty-six healthy, full-term infants participated in our study. They included thirty-seven 6-month-olds (mean age = 6 months 15 days; 20 males, 17 females), forty-six 9-month-olds (mean age = 9 months 14 days; 33 males, 13 females), forty-one 12-month-olds (mean age = 12 months 8 days; 16 males, 25 females), and forty-two 15-month-olds (mean age = 15 months 20 days; 22 males, 20 females). An additional 11 infants were tested but excluded from the final analysis because of failure to complete a minimum of 20 trials (5 infants), fussiness (3 infants), or apparatus malfunction (3 infants). The infants were recruited through letters to parents in Davis, California. The institutional review board at the University of California, Davis, approved the experimental protocol, and informed consent was obtained from a parent or caregiver of each infant.

Stimuli and apparatus. Stimuli consisted of 10 Mooney faces (Fig. 2a), 5 of which were from Mooney's (1957) original study. Mooney faces lack clearly identifiable individual facial features and cannot be perceived using bottom-up processes, such as parsing or segmenting. Because no bottom-up cues exist to distinguish the cast shadows in a Mooney face image, in order to find any facial feature, such as an eye or a nose, one must first perceive the image holistically as a face (Cavanagh, 1991; Kemelmacher-Shlizerman, Basri, & Nadler, 2008; Moore & Cavanagh, 1998). Adults have more difficulty recognizing faces in Mooney images than in gray-scale photographs

Fig. 2. Mooney face stimuli shown to participants in Experiment 1. All faces used were cropped to fit ellipses, as shown in (a). The top row in (a) includes original faces used in Mooney's 1957 study. On each trial, one upright face and one inverted face were presented. In the uncrowded condition (b), these two faces were displayed by themselves, and in the crowded condition (c), six flanker images surrounded each face. Eccentricity of the faces was varied; in the examples shown here, the faces are at 3° eccentricity.

of faces. Mooney faces are more easily and rapidly identified as faces when they are in an upright orientation than when they are in an inverted orientation, and upright Mooney faces activate known face-selective regions such as the fusiform face area (FFA; Andrews & Schluppeck, 2004; George, Jemel, Fiori, Chaby, & Renault, 2005; Latinus & Taylor, 2005). Studies report that infants look longer at upright Mooney faces than at inverted Mooney faces (Doi, Koga, & Shinohara, 2009; Leo & Simion, 2009).

All Mooney face stimuli used in the experiment were images with 99.77% Michelson contrast and were cropped to fit into a 3° × 5° ellipse (see Fig. 2a) when viewed from a distance of 60 cm. In the uncrowded condition, participants viewed Mooney faces without flankers (see Fig. 2b). For the crowded condition, six smaller flanker images (1.05° × 1.53°) were created by cutting elliptically shaped sections from each upright target face. These flanking images were randomly positioned around the target face (i.e., the face that they were cut out from) at a fixed horizontal distance (2.2° between the center of the Mooney face and the center of each flanker image; see Fig. 2c). All stimuli were presented against a gray background (77.23 cd/m^2).

The experiment was conducted in a testing room with the lights switched off. Stimuli were presented on a Tobii (Tobii Technology AB, Danderyd, Sweden) 17-in. LCD binocular eye-tracker monitor (resolution of 1024 × 768 pixels, 50-Hz capture rate, 60-Hz refresh rate). The experiment was programmed and presented using Presentation software, Version 11.3 (Neurobehavioral Systems, Inc., Albany, CA).

Procedure. The experiment began with a five-point calibration of the eye tracker so that the infant's gaze position during the task would be estimated accurately. Following calibration, the experiment began with a video containing a dynamic colored image (1° in diameter) that was paired with a synchronous sound and presented at the center of the screen until the infant fixated on the image, at which point the experimenter started the trial. A gaze that was positioned anywhere within a radius of 2° around the central fixation image was considered to be central fixation. A trial in which an infant did not fixate within 10 s, or shifted his or her gaze away from fixation before the stimuli appeared, was discarded (an average of seven trials per participant).

On each trial, participants were shown two images of the same Mooney face, one upright and one inverted, to the left and right of fixation. The distance from the center of the fixation image to the center of each of the Mooney faces was 3°, 6°, or 10° along the horizontal meridian. The two faces were presented either without any flanking images (uncrowded condition) or with corresponding flanker images (crowded condition) for a duration of 2 s. The eccentricities at which the faces were presented were blocked in sets of four trials, and the order of blocks was randomized for each infant. The visual field in which the upright face appeared (i.e., left or right) and the presence or absence of flankers were randomized on each trial. Testing was terminated if the infant did not meet fixation criteria for five consecutive trials or became fussy.

Coding and threshold estimation. Eye-tracking data was coded offline using Noldus Observer 5.0 software (Noldus Information Technology, Wageningen, The Netherlands). The primary measure of performance on each trial was the infant's first saccadic eye movement from the central fixation image immediately following the presentation of the faces. First saccades were coded as a hit (1) if the fixation landed on the upright face of the pair and as a miss (0) if the fixation landed on the inverted face of the pair. In order to make a first saccade to the upright face, infant must have perceived and discriminated the upright face in their visual periphery. Each infant's performance was therefore calculated as the proportion of first saccades that the infant made to the upright face. Trials in which the infant's gaze remained at the center of the screen and trials in which the infant made a saccade to a screen area not containing a face were given a score of .5, on the assumption that these results did not indicate discrimination between the stimuli.

To confirm that crowding did not occur when the flanked faces were viewed foveally, we calculated an upright-face-preference score for each trial, based on the proportion of time the infant spent foveating the upright face. This score was calculated by dividing the length of time an infant spent fixating the upright face by the total time the infant spent fixating both the upright and the inverted faces. Each score ranged from 0 (the infant never looked at the upright face) to 1 (the infant looked only at the upright face), with .5 considered the chance level. The average preference score across the three eccentricities was used as a measure of foveal (0°), or free-viewing, performance because the infant's gaze was directly on the face and therefore the image must have been foveal.

A logistic function was fit to each infant's average performance across eccentricities (see Fig. 3) using the Psignifit toolbox software for MATLAB (The MathWorks, Natick, MA) and the maximum likelihood estimation procedure described by Wichmann and Hill (2001). The performance level at which we defined the threshold performance was the eccentricity value yielding a performance score of .75. To estimate parameters, threshold, slope, and error, we used a bootstrapping technique that included 5,000 replications for each fitted function. The criterion for including infants in the analyses was the goodness of fit of the fitted function, evaluated using deviance (Wichmann & Hill, 2001). Individual infants' face-discrimination threshold values were then used to calculate age-group averages and compare group performance in the uncrowded and crowded conditions.

Results and discussion

A 4 (eccentricity: 0°, 3°, 6°, or 10°) × 2 (condition: uncrowded or crowded) × 4 (age group: 6, 9, 12, or 15 months) repeated measures analysis of variance (ANOVA) was conducted on

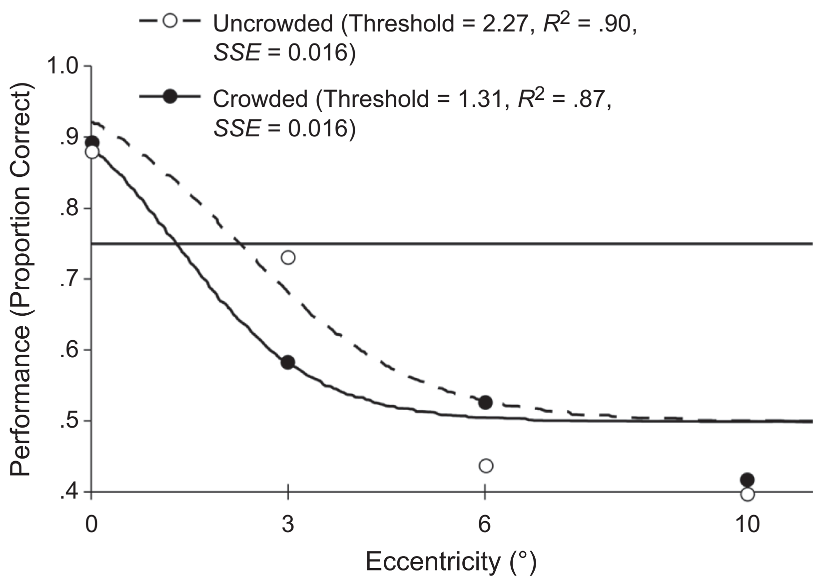

Fig. 3. Example psychometric functions from a 12-month-old infant. Performance is shown as a function of eccentricity for the uncrowded and crowded conditions. The eccentricity at which a performance score of .75 was obtained, indicated by the horizontal line intersecting both curves, was used as a measure of the threshold for face orientation discrimination. *SSE* = sum of squares of errors.

performance (upright-face-preference score at 0° and first-saccade score at 3°, 6°, and 10°). This analysis yielded a significant main effect of eccentricity, $F(3, 160) = 125.9$, $p = .0001$, $\eta^2 = .703$, and condition, $F(1, 162) = 101.1$, $p = .0001$, $\eta^2 = .384$. We also observed a significant interaction between eccentricity and condition, $F(3, 160) = 3.823$, $p = .011$, $\eta^2 = .067$. There was no main effect of age group, $F(3, 162) = 0.51$, $p = .676$, $\eta^2 = .009$, and therefore performance was collapsed across all infants for the subsequent analyses. All *p* values reported were Bonferroni-corrected for multiple comparisons. To examine the interaction, we performed a set of planned comparisons using pair-wise *t* tests (two-tailed). These tests revealed that at 3° of eccentricity, infants performed significantly better in the uncrowded condition ($M = .63$, $SD = .15$) than in the crowded condition ($M = .59$, $SD = .18$), $t(165) = 2.336$, $p = 0.021$, $SEM = 0.018$. At 6° and 10° of eccentricity, infants' performance was no different from chance in either the uncrowded or the crowded condition.

To test the magnitude of the effect of crowding at 3° on individual infants, we calculated a difference score for each infant by subtracting the first-saccade performance on crowded trials from the first-saccade performance on uncrowded trials. Overall, the difference scores were significantly positive, $t(165) = 2.350$, $p = .020$, $SEM = 0.018$, confirming that the flanking images did affect peripheral face discrimination at 3°. These results demonstrate that infants' ability to discriminate the orientation of a Mooney face in the visual periphery decreased as a function of eccentricity, and was significantly worse in the crowded condition than in the uncrowded condition. Flankers did not, however, impair discrimination of the upright face when it was viewed foveally, $t(165) = -1.379$, $p = .170$, $SEM = 0.014$. This result is consistent with the definition that crowding does not occur at the fovea, and that crowding can be distinguished from a masking process that prevents both detection and identification, independently of eccentricity (Pelli et al., 2004).

As we observed a significant effect of eccentricity on performance, we calculated individual infants' face discrimination thresholds separately in the uncrowded condition and the crowded condition. The final sample of infants whose fitted functions met the goodness-of-fit criterion included nineteen 6-month-olds, twenty-one 9-month-olds, sixteen 12-month-olds, and twenty-one 15-month-olds. Representative psychometric functions from a 12-month-old infant are shown in Figure 3. Box-plot analyses revealed a skewed distribution of threshold values in all age groups. Because of this nonnormality, we calculated a trimmed mean threshold by removing the lowest 20% and highest 20% of the distribution for each age group. Comparing groups based on trimmed means is advantageous when distributions are skewed (as is often the case with infant data), because the technique provides a robust estimate of the most common observation and reduces the effects of extreme values in a sample (Wilcox, 2005).

To assess how infant eccentricity thresholds varied with age, we conducted one-way ANOVAs of thresholds in the uncrowded and crowded conditions, with age group (6, 9, 12, or 15 months) as a between-subjects factor. There was a significant main effect of age on thresholds in the crowded condition, $F(3, 66) = 2.749$, $p = .050$, $\eta^2 = .439$, reflecting higher (i.e., better) eccentricity limits in 15-month-old infants than in the other three age groups; age did not have an effect on thresholds in the uncrowded condition (see Fig. 4). Pair-wise *t* tests (two-tailed) showed significantly lower eccentricity limits in the crowded condition than in the uncrowded condition for two age groups: 9-month-olds, $t(16) = 2.622$, $p = .016$, $SEM = 0.093$, and 12-month-olds, $t(13) = 2.335$, $p = .029$, $SEM = 0.189$.

These results demonstrate that infants can discriminate the orientation of a Mooney face to a limited extent in their peripheral visual field. It is important to note that the significant interaction between eccentricity and crowding establishes that flanking images interfered with infants' ability to discriminate the upright face in their visual periphery, a finding consistent with the established definition of crowding. We observed the effect of crowding as close as 3° from central fixation in infants of all ages. Crowding could not be evaluated at eccentricities greater than 3° because performance dropped to chance levels. Threshold values for the discrimination of uncrowded faces did not vary with age, whereas thresholds for the discrimination of crowded faces were significantly better in 15-month-olds than in other age groups, indicating that the resolution of conscious visual perception increased from 6 months to 15 months. However, as a result of the greater improvement in thresholds in the crowded condition, the relative difference in threshold performance between uncrowded and crowded faces was not statistically significant in 15-month-olds (although the trend was in the expected direction across age), possibly because of a lack of statistical power. As expected, one consequence of the developmental change in resolution observed in 15-month-olds was increased variability in performance as a group. Overall, by 15 months of age, infants' spatial resolution of vision was found to be approximately twice as coarse as the spatial resolution measured with the same stimuli in adults (Farzin et al., 2009).

Experiment 2

In Experiment 1, infants' ability to discriminate the orientation of the uncrowded face decreased with eccentricity, most probably as a result of crowding of the facial features, as found in studies of face crowding in adults (Farzin et al., 2009; Martelli, Majaj, & Pelli, 2005). It could also be argued, however, that the drop in performance that we observed was partially the result of infants' reduced visibility of faces in their visual periphery. In Experiment 2, we aimed to determine whether discrimination of an uncrowded Mooney face in the periphery could be improved by increasing the size of the face, which would rule out acuity as the primary limit on conscious vision. We also aimed to determine whether the crowding effect would still be present when peripheral discrimination performance was restored.

Method

Participants. Eleven healthy, full-term infants participated in the study (mean age = 6 months 17 days; 5 males, 6 females). Infants were recruited through fliers, letters to parents, and word of mouth in Davis, California. The institutional review board at the University of California, Davis, approved the experimental protocol, and informed consent was obtained from a parent or caregiver of each infant.

Stimuli and apparatus. Stimuli in Experiment 2 were the same Mooney faces and flanking images used in Experiment 1, except that face size was scaled up by a factor of 3 to fit a 10° × 15° ellipse at a viewing distance of 60 cm. Flanking images were also scaled by a factor of 3, such that they fit into

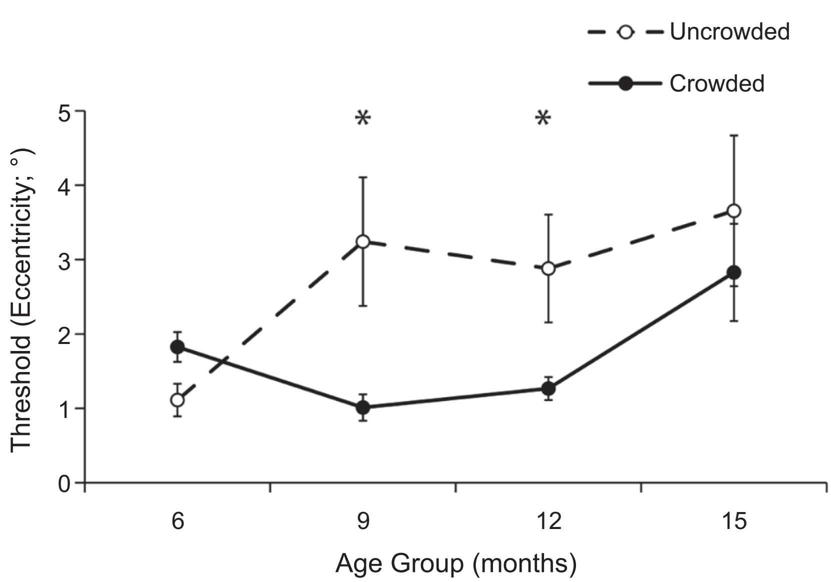

Fig. 4. Graph illustrating the effect of crowding on discrimination of face orientation in 6-, 9-, 12-, and 15-month-old infants. The mean visual threshold (eccentricity) for orientation discrimination of a Mooney face is shown as a function of age group in the uncrowded and crowded conditions. Asterisks indicate significant differences in pair-wise comparisons between conditions for a given age group ($p < .05$). Error bars represent ±1 *SEM*.

a 3° × 4.75° elliptical area. To remove overlap between central fixation and the most foveal flankers, and to ensure that the most peripheral flankers were visible on the screen, we included four flankers, rather than six, in the crowded condition. These flanking images were presented surrounding the faces at a fixed horizontal center-to-center distance of 7°. The apparatus used was identical to that described for Experiment 1.

Procedure. The procedure used in Experiment 2 was identical to that used in Experiment 1, except that one upright and one inverted face were shown 10° to the left and right of fixation, along the horizontal meridian.

Coding. As in Experiment 1, each infant's first saccadic eye movement from the central fixation was coded, and discrimination performance was calculated as the proportion of first saccades made to the upright face.

Results and discussion

Infants' orientation discrimination performance with larger uncrowded faces presented at 10° was significantly better than infants' performance with smaller faces at 10° (in Experiment 1), $F(1, 176) = 42.98$, $p = .0001$, $\eta^2 = .197$. Furthermore, infants' performance with the larger uncrowded faces at 10° was equivalent to infants' performance in Experiment 1 with smaller uncrowded faces at 3° (Fig. 5a), which suggests that infants can distinguish an upright face at 10°. The effect of flankers was tested using a pair-wise *t* test (two-tailed), which revealed a significant difference between performance in the uncrowded and crowded conditions, $t(10) = 5.128$, $p = .0001$, $SEM = 0.036$, such that discrimination of larger faces in the presence of flankers did not differ from the chance level of .5, $t(10) = -1.096$, $p = .299$, $SEM = 0.011$ (Fig. 5a). Our finding that flankers around the large face at 10° reduced discrimination performance to chance confirmed that discrimination in the periphery was limited most fundamentally by crowding, and not just by visibility or acuity. Overall, increasing face size restored infants' discrimination performance in the periphery, and when the visibility of faces at 3° and 10° was equated, flanking images continued to impair recognition of the upright face. These results confirm that crowding imposes a coarser limit to peripheral object recognition than acuity.

We conducted an additional analysis to confirm that infant peripheral detection capabilities did not account for the drop in performance with eccentricity. We calculated the proportion of trials from Experiments 1 and 2 in which each infant's first saccade landed on one of the face images (either upright or inverted) in the uncrowded condition as a function of eccentricity. We expected that if infants were unable to detect the faces at more peripheral locations because of limitations in acuity, first-saccade localization accuracy would decline with eccentricity. This analysis indicated that infants were, in fact, able to detect and correctly localize the spatial position of the faces very precisely at each eccentricity, and irrespective of face size at 10° (Fig. 5b). Thus, as in adults, acuity is not the main limiting factor for peripheral visual awareness in infants—crowding is.

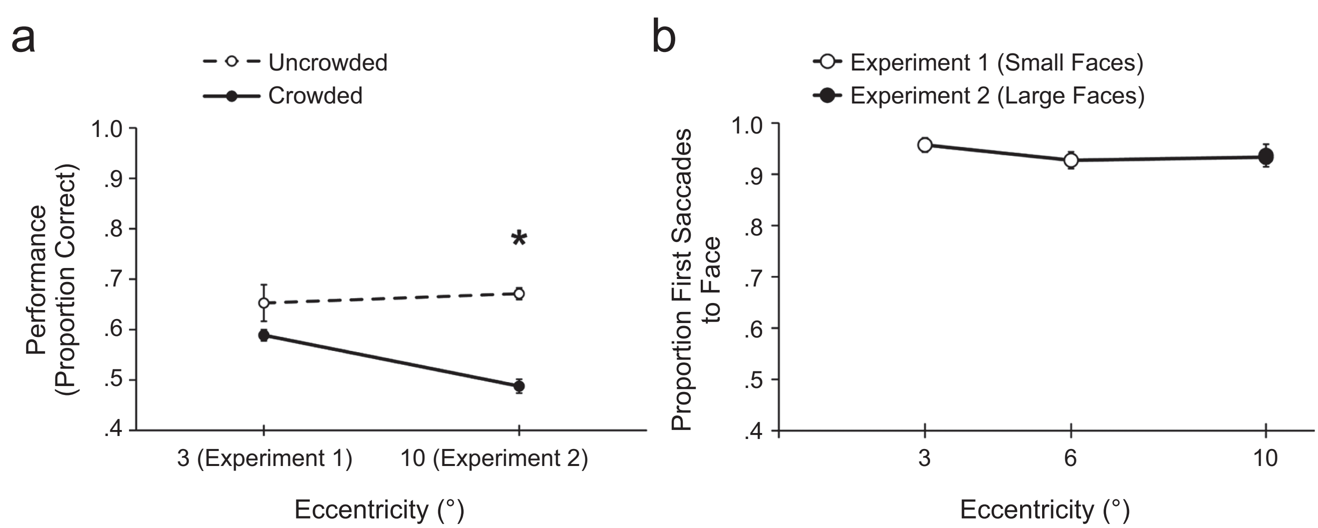

Fig. 5. Discrimination and detection of small and large Mooney faces at different eccentricities. The graph in (a) shows infants' orientation discrimination performance as a function of face size and eccentricity (small faces at 3° eccentricity in Experiment 1 and large faces at 10° eccentricity in Experiment 2) in the uncrowded and crowded conditions. The graph in (b) shows the proportion of trials in the uncrowded condition in which a face (either upright or inverted) was correctly localized as a function of face size and eccentricity. Note that the data points for Experiments 1 and 2 at 10° eccentricity overlap. The asterisk indicates a significant difference in a pair-wise comparison of the crowded and uncrowded conditions ($p < .05$). Error bars represent ±1 *SEM*.

General Discussion

Crowding limits conscious visual perception of individual objects in naturally cluttered scenes, thereby defining the window of object recognition in the periphery. Our study measured the effective spatial resolution of peripheral visual perception in infants. Experiment 1 established that infants between the ages of 6 months and 15 months can recognize a Mooney face in their visual periphery. Our results demonstrate that the presence of surrounding flankers significantly reduced this ability for stimuli as close as 3° of eccentricity. Infants' face discrimination thresholds revealed a spatial resolution of conscious perception twice as coarse as that of adults, which substantially limits what an infant can perceive in a peripheral scene. Unlike adults, who employ a fine-grained visual spotlight to access peripheral information, infants appear to have a more diffuse lantern of visual awareness that sets the limit on what can be registered and accessed in the periphery. Studies showing immature acuity and contrast sensitivity suggest that an infant's visual experience is simply more blurred than that of adults. However, our results suggest that an infant's visual world may also include more of a jumbled mass of unbound features than an adult's visual world.

Our results confirm that infants' inability to recognize a face in the presence of flanking images was the result of crowding, and not reduced visibility or some other phenomenon. Each pair of Mooney faces shown to infants differed only in orientation, ensuring that discrimination was not based on low-level visual cues, such as differences in internal elements or mean luminance. The primary measure—the first saccadic eye movement from central fixation to one of the faces—ensured that perception of the face relied on peripheral vision, and that the flanking images did not simply distract the infant from the face. Infants' discrimination of the uncrowded upright face in the periphery was restored when face size was increased; in the presence of flankers, however, the face was still crowded and unrecognizable. Taken together, these results are the first quantitative measure of the effect of crowding on infant visual perception.

The finding that young infants experience a much coarser resolution of conscious visual perception in comparison with adults has several implications for understanding visual and visuomotor development. First, our finding illustrates that the limit of peripheral awareness in infants is experience dependent. Regardless of the neural mechanism or mechanisms used to explain crowding, this fundamental limit on object recognition is the result of a developmental process. That is, the size of the spotlight, or window, that defines the spatial resolution of visual awareness is flexible, and may shrink during a specific developmental period, improving peripheral recognition of cluttered scenes over time, until adult levels of spatial resolution are reached. This has further implications for visually guided action in the presence of clutter, or crowding. Because eye movements and reaching movements often require peripheral recognition of individual objects, limited visual spatial resolution may influence or constrain goal-directed actions that can be executed to the periphery (Bulakowski, Post, & Whitney, 2009). The limited spatial resolution of peripheral perception may contribute to age-related changes in the frequency of eye movements in infancy (Salapatek, Aslin, Simonson, & Pulos, 1980).

An intriguing question that arises from this study is whether infants' limited visual awareness represents more spatial coverage at the expense of reduced resolution, and, if so, whether reduced resolution is actually advantageous for infants. For example, some evidence suggests that whereas crowding blocks access to individual identities in the visual periphery, access to gist or ensemble statistics is preserved (Haberman & Whitney, 2007; Larson & Loschky, 2009; Parkes, Lund, Angelucci, Solomon, & Morgan, 2001). Therefore, limited conscious access to individual objects in cluttered scenes may serve a useful purpose for young infants, by allowing them to extract information about the gist of a scene in a computationally efficient and unencumbered way.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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