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Perceptual learning and face processing in infancy

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Abstract

Configural information (spacing between features) contributes to face-processing expertise in adulthood. We examined whether infants can be “trained” to process this information. In Experiment 1, 3.5-month-olds failed to discriminate changes in the spacing between facial features. However, in Experiments 2 and 3, infants processed the same information after being primed with faces in which the spacing was repeatedly altered. Experiment 4 found that priming was not effective with inverted faces or with faces depicting changes in features but not relations among features, indicating that the priming exhibited in Experiments 2 and 3 was specific to upright faces depicting spacing changes. Thus, even young infants who do not readily process facial configural information can be induced to do so through priming. These findings suggest that learning to encode critical structural information contributes to the development of face processing expertise.

Keywords

configural face processing; infancy; perceptual learning; priming; social cognition

1. INTRODUCTION

It is commonly accepted that early experiences have a significant impact on human development. Carolyn Rovee-Collier understood this early in her career and made it one of her life’s missions to reveal memory processes that underlie the effects of experience on development (Rovee-Collier, 1999; Rovee & Rovee, 1969). Key challenges in this endeavor include attempting to create specific experiences in the laboratory, coaxing infants to reveal what they remember about the experience, and documenting the effects of this experience on subsequent behavior. Carolyn Rovee-Collier’s genius lay in using a naturalistic and engaging task, the mobile-conjugate reinforcement procedure, for this purpose. The success of this approach is clearly evident in the vast amount of information that her work has revealed about the manner in which memory processes mediate the effects of experience on development.

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The research reported in this paper also tries to understand the effects of experience on cognitive development. Specifically, we used a priming procedure to model how infants learn to process a key aspect of faces. Faces play a significant role in social interactions by providing a wide variety of important information about people, including identity, gender, race, and emotion. Research suggests that expertise in face processing allows adults to adaptively utilize this information (Maurer, LeGrand, & Mondloch, 2002; McKone, 2010; McKone & Robbins, 2011; Mondloch, LeGrand, & Maurer, 2010). Virtually all models of face-processing development assume that extensive experience with faces in infancy contributes to the development of this expertise (e.g., Acerra, Burnod, & de Schonen, 2002; Johnson, 2011; Nelson, 2003; Pascalis & Kelly, 2009; Simion, Di Giorgio, Leo, & Bardi, 2011). For example, Morton and Johnson (1991) explicitly argue that the cortical CONLERN system that underlies the development of face processing during the first few months of life is largely driven by experience with conspecifics.

Many studies have documented the effects of experience on the development of face processing in infancy. For example, race-based specialization in the form of preference for own-race faces, better discrimination between own-race faces than between other-race faces, and asymmetries in detection of own-race versus other-race faces has been demonstrated in infancy (e.g., Anzures et al., 2013; Hayden, Bhatt, Zieber, & Kangas, 2009; Hayden, Bhatt, Kangas, Zieber, & Joseph, 2012; Kelly et al., 2005, 2007; Sangrigoli & de Schonen, 2004). Similarly, specialization on own-species (e.g., Pascalis, de Haan, & Nelson, 2002), and female (e.g., Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002; Ramsey-Rennels & Langlois, 2006) faces, as well as studies indicating that these specializations can be modified through exposure (e.g., Anzures et al., 2012; Heron-Delaney et al., 2011; Sangrigoli & de Schonen, 2004; Scott & Monesson, 2009), clearly illustrate the impact of experience on the development of face processing. Further evidence of the critical role of experience in face-processing development comes from studies documenting the deleterious effects of cataracts that affect vision in infancy on subsequent face processing (e.g., Le Grand, Mondloch, Maurer, & Brent, 2001; Maurer, Mondloch, & Lewis, 2007).

However, while many studies have suggested an important role for experience in the development of face processing, they do not directly address the question of whether experience induces infants to process the relevant information in faces that underlies expert face processing by adults. We examined this issue in the current study by testing whether young infants can be primed to process relational information, which is frequently associated with face processing expertise.

The relational information we address is *configural* information, which, along with featural information and other kinds of relational information, has been demonstrated to contribute to expert face processing by adults (Carey & Diamond, 1994; Carey, De Schonen, & Ellis, 1992; Maurer et al., 2002; McKone & Robbins, 2011; Mondloch & Thomson, 2008). Configural information (also referred to as *second-order* relations) refers to the spatial relations between facial features (e.g., the distance between eyes). The current study examined whether 3.5-month-olds, who do not readily process configural relations, can be trained to encode this information. If so, it would suggest that learning directs infants'

attention to this critical characteristic of faces and drives the development of configural information processing that contributes to expert processing in adults.

The association of configural information with face processing expertise comes from studies in which participants exhibit superior sensitivity to this information in human faces than in other stimuli. For instance, Mondloch, Maurer, and Ahola (2006) found that adults are more accurate at processing spacing changes in human faces than in monkey faces. Similarly, adults process spacing information in face stimuli much more accurately than in house stimuli (Leder & Carbon, 2006; Robbins, Nishimura, Mondloch, Lewis, & Maurer, 2010). Robbins et al. (2010) report, for example, that spacing changes have to be four times as large in house stimuli as in human face stimuli for adults to exhibit the same level of discrimination. Further, Cassia, Turati, and Schwarzer (2011) reported that 4-year-olds rely more on spacing information when discriminating between faces than between cars. Moreover, Zieber et al. (2013) found that 5- and 9-month-olds detect spacing changes in faces but fail to detect equivalent changes in house stimuli.

Adults are also less accurate at identifying inverted compared to upright faces (e.g., Freire, Lee, & Symons, 2000; Leder, Candrian, Huber, & Bruce, 2001; Rossion, 2008; Valentine, 1988; Yin, 1969), and this deficit has been associated with configural information processing: some studies demonstrate that inversion affects configural information processing more than other types of information processing (e.g., Collishaw & Hole, 2000; Freire et al., 2000). It is thought that the deficit in configural information processing in inverted faces is due to the smaller degree of exposure to inverted compared to upright faces (Freire et al., 2000). Based on these findings, some researchers have concluded that configural information is, in fact, related to face-processing expertise because this kind of information is processed in the more commonly encountered upright faces than in the less common inverted faces (Freire et al., 2000; but see McKone & Yovel, 2009).

Given the importance of configural information in face processing, several studies have examined the development of this kind of relational information processing. There are many reports of configural information processing in faces by infants 5 months of age or older (e.g., Bhatt, Bertin, Hayden, & Reed, 2005; Hayden, Bhatt, Reed, Corbly, & Joseph, 2007; Thompson, Madrid, Westbrook, & Johnston, 2001; Zieber et al., 2013). Hayden et al. (2007b), for instance, found that 5-month-olds are sensitive to spacing changes in female faces. Zieber et al. (2013) extended these findings to spacing changes in male faces. However, very few studies have examined configural information processing before 5 months of age. Using a familiarization paired-comparison procedure in which infants were exposed to a female face and tested for preference between this face and another in which the spacing between features was altered, Bhatt et al. (2005) found that 3-month-olds do not process configural changes (differences in spacing between eyes and between mouth and nose) under conditions in which 5-month-olds do. Bhatt et al. (2005) also documented another failure on the part of 3-month-olds to process configural information: infants this age failed to exhibit a Thatcher illusion (i.e., superior discrimination of feature inversion in upright than in inverted faces, which has been associated with configural information processing; see Bartlett & Searcy, 1993; Maurer et al., 2002; Murray, Yong, & Rhodes, 2000). In contrast, 6-month-olds did exhibit a Thatcher illusion in Bertin and Bhatt (2004).

Based on the different kinds of failure to process configural information at 3 months, Bhatt et al. (2005) concluded that configural information processing develops between 3 and 5 months of age.

Conversely, a study by Quinn and Tanaka (2009) claimed that 3- to 4-month-olds are, in fact, sensitive to configural information in faces. In their study, infants were familiarized to grayscale photographs of faces and tested with images in which the configural information was manipulated. Specifically, either the distance between the eyes or the distance between the nose and mouth was changed. Quinn and Tanaka (2009) found that 3- to 4-month-olds are sensitive to the configural changes in these stimuli. It is possible, however, that the infants in that study discriminated because the configural changes resulted in unnatural faces that were outside of physiognomic norms. Indeed, neither Bhatt et al. (2005) nor Quinn and Tanaka (2009) tested young infants with spacing changes that were within population norms (such as the range of space among features of Caucasian faces in a Canadian City documented by Farkas, 1994). Thus, it is unclear whether infants younger than 5 months of age are sensitive to configural differences across faces that might be encountered in typical populations.

Mondloch et al. (2010) suggested that general changes in perceptual abilities such as Vernier acuity and spatial integration may account for developmental changes in configural face processing in childhood. It is possible that infants younger than about 5 months of age have not developed the perceptual capacity to process subtle spatial information in faces. Alternatively, even young infants may be capable of processing this information but do not readily do so. We tested these possibilities in the current experiments.

In Experiment 1 of the current set of studies, we examined 3.5-month-olds' sensitivity to configural information changes in faces that fall within population norms. That is, we tested infants' discrimination of spacing changes that followed Farkas' (1994) anthropomorphic norms for Caucasian male and female faces such that both the undistorted and spacing-changed faces fell within the normal range for Caucasian faces. Then in Experiments 2 and 3, we examined whether priming infants with faces in which spacing information is changed allows them to subsequently process configural information in novel faces. In Experiment 4, we tested the specificity of priming found in Experiments 2 and 3 by examining whether exposure to inverted faces and faces in which features changed, but configural relations did not, also facilitate learning.

We chose to examine the role of priming in the development of configural information processing because prior research has found that priming facilitates the processing of various kinds of perceptual information in infancy (e.g., Baillargeon, 2004; Baillargeon, Weiting, & Yuan, 2009; Johnson & Shuwairi, 2009; Needham, 2000; Needham, Barrett, & Peterman, 2002; Wang & Baillargeon, 2008; Wilcox, Smith, & Woods, 2011; Wilcox & Woods, 2009). For instance, 4-month-olds do not normally anticipate the correct position of an object moving along a trajectory if its movement is partially occluded. However, Johnson and Shuwairi (2009) found that 4-month-olds can be "trained" to anticipate correctly if, prior to being tested, they are exposed to a fully visible object moving along the trajectory. Similarly, Wang and Baillargeon (2008) were able to "teach" 9-month-olds to reason about the ability

of tall versus short containers to cover objects by exposing them to contrasting covering events prior to being tested. We reasoned that young infants can similarly be trained to process configural information in faces if they are exposed to conditions in which this information is highlighted. We tested this proposal in Experiments 2 and 3.

2. EXPERIMENT 1

We examined 3.5-month-olds' sensitivity to configural information in faces in Experiment 1. As previously noted, there is a discrepancy in the literature regarding infants' sensitivity to configural information at this age (Bhatt et al., 2005; Quinn & Tanaka, 2009). Moreover, no prior study has investigated whether 3.5-month-old infants are sensitive to configural differences across faces within the range seen in typical populations (Farkas, 1994). We addressed these issues in Experiment 1 by testing infants' discrimination of changes in the spacing among facial features in color photographs, with spacing differences falling within the normal range of physiognomic differences in the general population (Farkas, 1994; see description in Method section). Moreover, we tested infants on both male and female faces. Although several studies have examined infants' sensitivity to spacing changes in female face images (e.g., Bhatt et al., 2005; Hayden, Bhatt, Joseph, & Tanaka, 2007; Thompson et al., 2001), to our knowledge, Zieber et al. (2013) is the only previous study to examine infants' processing of configural information in male faces. Even in that study, however, the youngest infants tested were 5 months of age, whereas 3.5-month-olds were tested in the current experiment. Thus, Experiment 1 sought to extend the generality of prior findings while examining whether young infants are sensitive to differences in spacing between facial features seen in typical populations.

Infants were initially familiarized to either an undistorted face or its configurally altered counterpart. Then, they were exposed to both faces concurrently during test trials to examine whether they discriminate between the two faces.

2.1. Method

2.1.1. Participants—Twelve 3.5-month-old infants (seven females, mean age = 106.75 days, SD = 9.89) participated in this experiment. An additional infant's data were excluded due to failure to sample both test stimuli. Infants were recruited via birth announcements published in the local newspaper and from a university hospital. Infants in this and the following experiments were predominately Caucasians from middle-class families. Preliminary analyses failed to find any differences in infants' performance as a function of race or ethnicity. Therefore, the scores of all infants were combined in the analyses reported in this paper.

2.1.2. Stimuli—The stimuli used in this experiment were color photographs of two male and two female faces obtained from the MacBrain face set (Tottenham et al., 2009; face numbers 06, 09, 21, and 24). Using Adobe Photoshop CS, the configural information of each image was manipulated to affect the eye and mouth regions. Specifically, as shown in Figure 1, the eyes were moved further apart and the mouth was moved down toward the chin, similar to the changes made in many prior studies that have examined configural information processing (e.g., Bhatt et al., 2005; Freire et al., 2000; Hayden et al., 2007; Mondloch, Le

Grand, & Maurer, 2002). Alterations made to the faces followed Farkas' (1994) anthropomorphic norms for Caucasian male and female faces such that both the undistorted and spacing-changed faces fell within the normal range for Caucasian faces. For female face 06, the eyes were moved 3.5 mm and the mouth was moved 3 mm, which respectively correspond to changes of 1.15 and .3 standard deviations according to Farkas' (1994) norms. For female face 09, the eyes were moved 2.5 mm (1.09 SD) and the mouth was moved 5 mm (.57 SD). The eyes of male face 24 were moved 6 mm (2.22 SD) and the mouth was moved 3.5 mm (1.85 SD). Finally, the eyes in male face 21 were moved 8.5 mm (1.09 SD) and the mouth was moved 2 mm (.57 SD). The degree of changes was varied across stimuli, while still keeping the changes with Farkas' (1994) norms, in order to increase the generality of the findings.

2.1.3 Apparatus and procedure—Participants were tested in a chamber surrounded by floor-to-ceiling black curtains. They were seated approximately 45 cm from a 50 cm computer monitor, which was the only source of light in the chamber. A Sony CCD-FX430 camera located on top of the monitor and a DVD recorder located outside the chamber were used to monitor and record infant's performance for later off-line coding.

Infants were tested using a visual paired-comparison procedure used in many previous studies (e.g., Pascalis et al., 2002; Zieber et al., 2013; Zieber, Kangas, Hock, & Bhatt, 2015). Each trial began with the presentation of an attention getter (rapidly alternating colorful shapes) in the center of the monitor. Once the infant oriented toward the attention getter, the experimenter pressed a button which led to its disappearance and the start of the familiarization trial. During the familiarization trial, two identical images were presented, one on each side of the monitor. They remained on the screen until the infant accumulated 30 s of looking time. Two 8 s test trials immediately followed the familiarization trial. During each test trial, the familiar image was paired with a novel image. For half of the infants, the familiar face was the original MacBrain face; for the other half of the infants, the familiar face was the corresponding configurally distorted face. Thus, across infants, the original and configurally distorted faces were equally often the novel and familiar stimuli during test. The location of the novel image during the first test trial was counter balanced across infants such that it was equally often seen on the right and left halves of the screen; furthermore, the left/right location of the novel stimulus was switched from one trial to the next. All infants were familiarized and tested with upright faces.

Infants' look direction and duration were coded offline by a coder blind to the left-right location of the novel stimuli, with the video playback slowed to 25% of normal speed. Data from 25% of infants were coded by a second coder to check for reliability. The Pearson correlation between the two coders was .92.

2.2 Results and discussion

The mean time required to accumulate 30 s of looking during familiarization is displayed in Table 1. This time did not differ as a function of the gender of the stimulus, $t(10) = 1.17$, $P = .27$, two-tailed. Thus, infants' looking was equally engaged by female and male faces during familiarization.

As in prior studies (e.g., Bhatt et al., 2005), a novelty percent preference score was computed. Each infant's total look duration to the novel image across the two test trials was divided by the total look duration to both novel and familiar stimuli across the test trials and multiplied by 100. Discrimination is assumed if the mean percent preference score is significantly different from the chance level of 50%.

Recall that infants in this experiment were tested on four different face pairs. Preliminary analyses failed to reveal any differences in performance across these four faces. Similarly, the variation across the individual faces did not affect performance in any of the following experiments. Thus, in all experiments, the analyses were collapsed across the individual face variable.

The data from Experiment 1 are presented in Table 1. There was no difference in infants' performance across the male and female face stimuli [$t(10) = 1.07$, $P = .31$, two-tailed, $d = .62$], thus the following analysis was collapsed across this variable. Infants' mean preference score of 51.51% did not differ significantly from the chance level of 50%, $t(11) = .67$, $P = .52$, two-tailed, $d = .40$ (Table 1). Thus, there was no evidence to indicate that 3.5-month-old infants detect configural spatial changes in faces when these alterations are within the range of differences seen in typical populations (Farkas, 1994).

3 EXPERIMENT 2

Given that infants in Experiment 1 failed to process spacing information in faces, in Experiment 2, we sought to examine whether infants can be primed to process this information. As noted in the Introduction, previous research has shown that infants can be trained to process information that they previously failed to encode (e.g., Heron-Delaney et al., 2011; Johnson, 2009; Needham & Baillargeon, 1998; Wilcox & Chapa, 2004). For example, young infants can be trained to attend to specific types of relational information by highlighting them in images (Baillargeon et al., 2009; Johnson & Shuwairi, 2009; Quinn & Bhatt, 2005). In Experiment 2, we examined whether infants can similarly be trained to process configural spatial relations among facial features by highlighting spacing changes in facial images. Infants were exposed to alternating undistorted and configurally distorted images, such that changes in the spatial relations among features were highlighted. After repeated exposure to such faces, infants were tested for their discrimination of spacing changes in yet another face in the same manner as in Experiment 1 (see Figure 2). That is, infants in Experiment 2 were tested exactly as in Experiment 1, except that prior to familiarization, infants were primed to attend to spacing changes by exposing them to different facial images in which the spacing between features changed repeatedly.

3.1. Method

3.1.1 Participants—Twelve 3.5-month-old infants (five females, mean age = 107.42 days, $SD = 9.59$) were recruited in the same manner as in Experiment 1. Infants were predominately Caucasians from middle-class families. Two additional infants' data were excluded due to a failure to sample both stimuli during test.

3.1.2 Stimuli—The stimuli were the same as those used in Experiment 1. In addition, two male and two female faces were selected from the MacBrain face set (Tottenham et al., 2009; face numbers 01, 07, 27, and 28). These additional stimuli were used as the priming stimuli. The configural information of each image was manipulated, as in Experiment 1, to affect the eye and mouth regions of the face (see Figure 1). For female face 01, the eyes were moved 5.5 mm and the mouth was moved mm, which respectively corresponds to changes of 2.22 and 1.85 standard deviations according to Farkas' (1994) norms. For female face the eyes were moved 5 mm (1.66 SD) and the mouth was moved 2.5 mm (.72 SD). The eyes of male face 27 were moved 6 mm (1.66 SD) and the mouth was moved 1.5 mm (1.12 SD). Finally, the eyes in male face 28 were moved 5.5 mm (.69 SD) and the mouth was moved 1.5 mm (1.46 SD). The familiarization and test stimuli were the same as in Experiment 1.

3.1.3 Apparatus and procedure—The apparatus and procedure were the same as in Experiment 1, with the only difference being the addition of two 10 s priming periods before familiarization in order to induce infants to attend to spacing changes in subsequently presented faces. During priming, a normal and configurally distorted face alternated at a rate of one face per second for 10 s in the center of the screen; phenomenologically, the eyes seem to move farther apart/closer together alternatively and the mouth move up/down from the nose on an individual face (see Figure 2). Infants were exposed to two such training faces before familiarization (10 s presentations of each of two different face pairs). The priming and subsequent familiarization/test faces were of the same gender but different individuals. For instance, an infant might see females A and B during priming, but be familiarized and tested with female C and its distorted/undistorted counterpart. Data from 25% of infants were coded by a second coder to check for reliability. The Pearson correlation between the two coders was .98.

3.2 Results and discussion

The mean time required to accumulate 30 s of looking during familiarization is displayed in Table 1. This time did not differ as a function of the gender of the stimulus, $t(10) = .14$, $P = .89$, two-tailed, $d = .08$. Thus, infants' looking was equally engaged by female and male faces during familiarization.

There was no difference in infants' performance across the male and female face stimuli [$t(10) = 1.44$, $P = .18$, two-tailed, $d = .82$] during the discrimination test, therefore the following analysis was collapsed across this variable. Infants displayed a preference score (mean = 44.52%) that differed significantly from the chance level of 50%, $t(11) = -2.31$, $P = .04$, two-tailed, $d = 1.39$ (Table 1). Moreover, infants' preference score in this experiment was significantly different from the preference score of the infants in Experiment 1 (mean = 51.51%) who were tested without any priming, $t(22) = -2.14$, $P = .04$, two-tailed, $d = .87$. Thus, priming infants to attend to spacing changes led infants to subsequently discriminate spacing changes on a different face. In contrast, in the absence of priming, infants in Experiment 1 failed to discriminate the same spacing changes.

It should be noted, however, that the evidence for discrimination in the priming condition came in the form of a *familiarity* preference rather than the typical novelty preference that is exhibited by infants in paired-comparison tasks. Logically, familiarity preference also indicates discrimination because it is not possible to exhibit a systematic preference (familiarity or novelty) without discrimination. Thus, the familiarity preference exhibited by primed infants compared to the lack of preference exhibited by infants without any priming is evidence that priming facilitates infants' discrimination of configural spacing changes in faces.

There are many instances in the literature in which familiarity preference has been used to infer discrimination (e.g., Bhatt, Hayden, Reed, Bertin, & Joseph, 2006; Fiser & Aslin, 2002; Johnson et al., 2009; Moore & Johnson, 2011; Roder, Bushnell, & Sassville, 2000; Walton & Bower, 1993). Whether infants exhibit novelty or familiarity preference is determined by a variety of factors, including stimulus complexity, infant age, and exposure duration (Cohen, 2004; Hunter & Ames, 1988; Oakes, 2010; Wagner & Sakovits, 1986). Thus, it is not clear why infants exhibited a familiarity preference in Experiment 2. Nonetheless, because the familiarity preference was unexpected, we aimed to replicate that preference in Experiment 3.

4. EXPERIMENT 3

4.1. Method

4.1.1. Participants—Eighteen 3.5-month-old infants (five females, mean age = 104.28 days, $SD = 7.74$) participated in Experiment 3. They were predominately Caucasians from middle-class families and were recruited in the same manner as infants in Experiments 1 and 2. Data from two additional infants were excluded due to a failure to sample both stimuli during test.

4.1.2. Stimuli, apparatus, and procedure—The stimuli, apparatus, and procedure were the same as those used in Experiment 2. Data from 25% of infants were coded by a second coder to check for reliability. The Pearson correlation between the two coders was .98.

4.2. Results and discussion

The mean time required to accumulate 30 s of looking during familiarization is displayed in Table 1. A *t*-test failed to reveal any differences in the time required to accumulate 30 s of exposure to female versus male faces, $t(16) = .38$, $P = .71$, two-tailed, $d = .18$. Thus, there was no evidence to suggest differences during familiarization between male and female faces.

There was no difference in infants' performance across the male and female face stimuli [$t(16) = 1.03$, $P = .32$, $d = .49$] during the test trials, thus the following analysis was collapsed across this variable. As in Experiment 2, infants displayed a familiarity preference score (mean = 43.13%) that significantly differed from the chance level of 50%, $t(17) = -2.07$, $P = .027$, one-tailed, $d = 1.01$ (Table 1). Thus, the results of this experiment replicated

the findings of Experiment 2 and once again indicated that young infants can be primed to process configural information in faces.

5. EXPERIMENT 4

In this experiment, we examined the specificity of learning exhibited by infants in Experiments 2 and 3. Recall that infants in those experiments discriminated spacing changes in facial stimuli after being exposed to faces in which the spacing between features were repeatedly altered, whereas infants in Experiment 1 who had no priming experience failed to discriminate the same changes. It is possible that any kind of previous exposure to faces or to configural changes in stimuli right before testing can induce subsequent discrimination of configural changes. In other words, it is not clear whether infants' learning in Experiments 2 and 3 was due to the following: (i) specific priming with configural information similar to the spacing changes on which they were subsequently tested; (ii) general exposure to faces; (iii) experience with any kind of non-specific configural changes; or (iv) general priming of the individual features (eyes and mouth) that were involved in the configural changes but not necessarily the spatial relations among features.

To address these issues, we examined the performance of two groups of infants in Experiment 4. One group of infants was primed with inverted faces with changing configural information (in contrast to priming with upright faces in Experiments 2 and 3). Inversion has previously been shown to affect relational processing in faces (e.g., Bartlett & Searcy, 1993; Bhatt et al., 2005; Collishaw & Hole, 2000; Hayden et al., 2007; Maurer et al., 2002; Mondloch et al., 2010; Zieber et al., 2013). If infants who are primed with inverted alternating faces fail to discriminate, then it would indicate that just any kind of exposure to changes in spacing information or to the features involved in the spacing changes is not enough to prime configural processing in infancy. We chose to prime infants with inverted faces because they matched the upright faces in all respects but for the orientation. This provided us with the best opportunity to test infants in this condition with stimuli that were as similar as possible to those used in Experiments 2 and 3.

The second control group was primed with faces in which the features that were involved in the spacing relations (eyes and mouth) were changed but not the spacing relations among them. Specifically, the colors of the eyes and of the mouth were repeatedly changed during priming, but, unlike in Experiments 2 and 3 and in the inverted condition of this experiment, there was no change in the spacing among features. This control condition was included to examine whether infants' learning in Experiments 2 and 3 was due to enhanced attention to these features induced by the priming (which could have led them to attend to the spacing among these features) rather than due to specific exposure to spacing changes. If priming involving only the changes in features is sufficient to induce infants to subsequently process configural information, then it would indicate the learning is not specific to spacing changes. On the other hand, if infants fail to process spacing changes after priming with featural changes, then it would suggest that infants' learning is specifically driven by exposure to configural changes. Note that the feature changes used in this experiment were not limited to differences seen in typical populations. Instead, we exaggerated the feature changes in order to ensure that infants attended to these changes during priming. If despite these significant

changes to the relevant features during priming, infants subsequently failed to process configural information, then it would indicate that specific priming with spacing changes in necessary for infants to subsequently process configural information.

5.1. Method

5.1.1. Participants—Thirty-six 3.5-month-old infants (15 females, mean age = 107.64 days, $SD = 8.36$) participated in Experiment 3. They were predominately Caucasians from middle-class families and were recruited in the same manner as infants in Experiments 1–3. Data from two additional infants were excluded due to a failure to sample both stimuli during test ($n = 1$) and experimenter error ($n = 1$).

5.1.2. Stimuli—Infants in this experiment were primed, familiarized, and tested with the same stimuli used in Experiments 2 and 3. However, during the priming phase, infants in the *inverted priming* condition were exposed to inverted faces. Thus, infants in this condition saw the same faces and changes in spacing as infants in Experiments 2 and 3 during priming, except that the faces were rotated 180 degrees. For infants in *feature change priming* condition, the eyes and mouths of the faces used during priming repeatedly changed color at the same rate as the spacing changes during priming in Experiments 2 and 3 (see Figure 3); the overall size and position of the features did not change, so that no changes in spatial relations occurred during priming. For both groups, the stimuli used during familiarization and tests were exactly the same as those used in Experiments 1–3.

5.1.3. Apparatus and procedure—The apparatus and procedure were the same as those used in Experiments 1–3, with the exception that infants in the inverted priming condition were primed with inverted faces and those in the feature change condition were primed with feature changes rather than configural changes. The familiarization and test phases were exactly the same as in Experiments 2 and 3. Note that, as in Experiments 2 and 3, infants were familiarized and tested with different faces than those used during priming. Data from 25% of infants were coded by a second coder to check for reliability. The Pearson correlation between the two coders was .96.

5.2. Results and discussion

The mean time required to accumulate 30 s of looking during familiarization is displayed in Table 1. A stimulus gender (female, male) $\times$ condition (inverted, feature change) analysis of variance was conducted on the mean time required to accumulate 30 s of looking during familiarization. Neither the main effects of stimulus gender [$F(1, 32) = 2.29, P = .14, \eta_p^2 = .07$] and condition [$F(1, 32) = 3.45, P = .07, \eta_p^2 = .10$] nor the interaction between the two variables was significant [$F(1, 32) = .87, P = .36, \eta_p^2 = .03$]. Thus, there was no evidence to suggest differences during familiarization between male and female faces or between inverted and feature change conditions.

There was no difference in infants' performance across the male and female face stimuli [$t(34) = 1.06, P = .30, d = .35$] during the test trials, thus the following analysis was collapsed across this variable. Neither infants in the inverted priming condition nor those in the feature change condition exhibited a preference score that was different from chance [inverted:

mean = 50.27%, $t(17) = .11$, $P = .92$, two-tailed, $d = .05$; feature change: mean = 46.35%, $t(17) = -.89$, $P = .39$, two-tailed, $d = .43$; see Table 1].

Thus, infants failed to process relevant spacing information when primed with inverted faces and with featural changes. It is not the case that any kind of prior exposure to faces or to spacing changes in stimuli or to featural changes sans spacing changes facilitates young infants' subsequent processing of this kind of information in upright faces. Rather, infants' learning is quite specific to priming with spacing changes in upright faces.

6. GENERAL DISCUSSION

Spacing among features is a significant component of adults' face representation (e.g., Maurer et al., 2002; McKone, 2010; McKone & Robbins, 2011; Mondloch et al., 2010). In the current research, month-olds were primed to process this information by exposing them to facial images in which differences in spacing among features were highlighted. Infants primed with upright faces with spacing changes subsequently processed configural spacing information in novel faces, whereas those without priming experience or those primed with inverted faces or with upright faces in which featural information was changed failed to process such changes. These results suggest that experience with variation in spacing information contributes to the development of face processing expertise by enabling infants to process configural spacing information. More generally, the results provide empirical support to the common assumption of many models that learning contributes to the development of face processing.

The finding that infants can be trained to process specific attributes of faces is consistent with many models of the development of face-processing expertise (Acerra et al., 2002; Johnson, 2011; Nelson, 2003; Pascalis & Kelly, 2009; Simion et al., 2011). Although they differ in many details, the models generally assume that infants are born with a predisposition to attend to faces or images that have face-like characteristics, and that development after birth is driven by the extensive experience that infants have with faces. The present finding that 3.5-month-olds can be primed to process configural information in faces is consistent with the idea that experience induces infants to process subtle information in faces that adults readily utilize for expert face processing. In typical encounters with people, infants may notice differences in configural spacing information not only in faces of different individuals but also when the same individual adopts different expressions, such as frowning, which changes the space between eyebrows and other facial features, or smiling, which could change the distance between the mouth and other features. Presumably, like the priming demonstrated in the current experiments, repeated experience with such changes in configural information leads the developing infant to incorporate this characteristic into the corpus of cues that they use to differentiate between faces.

Our findings are also consistent with prior reports of general perceptual learning in infancy (e.g., Baillargeon et al., 2009; Bhatt & Quinn, 2011; Cohen, 2010; Fiser, 2009; Johnson, 2009; Meltzoff, Kuhl, Movellan, & Sejnowski, 2009; Woodward & Needham, 2009). An example of such learning is the finding by Quinn and Bhatt (2005) that 3.5-month-olds, who otherwise do not derive global gestalts using shape similarity, can be induced to do so by

exposing them to varying examples of stimuli that have similar global organization. Similarly, as noted earlier, Wang and Baillargeon (2008) were able to prime 9-month-olds to process relations between physical properties of objects that they otherwise do not appear to encode.

The specificity of the learning exhibited in the current research is also noteworthy. Recall that only infants primed with upright faces in which the spacing between the features changed subsequently processed configural information. In contrast, those primed with inverted faces or with faces in which there were featural but not spacing changes failed to exhibit evidence of learning. This suggests that particular kinds of priming experiences rather than general exposure affect the development of face processing.

The exact mechanism through which priming experiences induce infants to process critical cues in faces is not clear, however. One possibility is that priming directs the infants' attention to the relevant information in such a manner that they subsequently begin to attend to the information that they previously were not processing to the same extent (Baillargeon et al., 2009; Bhatt & Quinn, 2011; Johnson, 2009). This increased attention during initial encoding might then translate into better discrimination of changes in the now more salient information in novel faces. While this mechanism is a possibility, it should be noted that the current research did not directly assess infants' attention, so it remains an open question as to whether a change in attentional emphasis is the mechanism underlying the facilitating effects of priming that were documented in the current research. This question can be addressed in future research by documenting whether infants' scanning of faces systematically changes as a result of priming experience.

Another possibility is that even young infants routinely process configural information in facial images but do not respond to differences in this information when discriminating between faces. In other words, infants may not weigh configural information as much as adults when making similarity judgments. It is possible that adults' greater degree of experience with faces induces them to also take configural information into consideration when processing differences between faces. In contrast, young infants with less experience may not utilize this information as readily. Priming might increase the salience of configural information and induce infants to weigh this information more heavily.

Thus, the exact mechanism that underlies the priming effect seen in the current study is open to question. However, the results are clear in indicating that sensory limitations do not underlie young infants' lack of discrimination of configural changes. As noted earlier, Mondloch et al. (2010) (also see Robbins, Shergill, Maurer, & Lewis, 2011) suggested that general changes in perceptual abilities such as Vernier acuity and spatial integration may account for developmental changes in configural face processing in childhood. The current research indicates that, at least to the extent tested in these experiments, even very young infants have the basic sensory capacity to process configural information. Of course, this does not mean that the basic perceptual functions underlying configural information processing are fully mature in infancy, and it is quite possible that developmental changes documented in prior studies in childhood (for a review, see Mondloch et al., 2010) are a result of continued refinement of perceptual capacities like Vernier acuity.

The exact manner in which infants exhibited sensitivity to configural information in the current study is also noteworthy. In both Experiments 2 and 3, infants who had been primed with upright faces with spacing changes exhibited familiarity preferences. As noted earlier, many prior studies have relied upon familiarity preference to infer discrimination (e.g., Bhatt et al., 2006; Fiser & Aslin, 2002; Johnson et al., 2009; Moore & Johnson, 2011; Roder et al., 2000; Walton & Bower, 1993). A variety of factors, including the age of the infant, the degree of stimulus complexity, and the time of testing have been thought to determine whether infants exhibit familiarity or novelty preference (Cohen, 2004; Hunter & Ames, 1988; Oakes, 2010; Wagner & Sakovits, 1986). One such factor is the degree of familiarization. All else being equal, infants are more likely to exhibit familiarity than novelty preference with lesser degree of familiarity with stimuli. It is thus possible that infants in Experiments 2 and 3 may not have been sufficiently familiar with the face to which they were exposed during the 30 s familiarization period, leading to a familiarity preference during test. Additionally, proactive interference from the two priming faces that preceded the to-be-remembered face may have contributed to a lesser degree of familiarity with the latter face and subsequent familiarity preference during the discrimination tests. Further, it is possible that the subtle differences between the two test faces (which differed only in spacing relations) may have resulted in a high level of task complexity and tested the limits of young infants' capacity, resulting in familiarity preference.

The uncertainty about the reason for infants' exhibition of a familiarity preference in this study is an example of the difficulties associated with the study of cognitive development in infancy. To date, our field is unable to make specific predictions about when infants exhibit familiarity versus novelty preference, although, as noted earlier, we know that a variety of factors are associated with the exhibition of one or the other kind of preference (Cohen, 2004; Hunter & Ames, 1988; Oakes, 2010; Wagner & Sakovits, 1986). This kind of uncertainty, combined with the general difficulty of trying to get nonverbal infants to reveal what they know about the world, is a continuing challenge to infancy researchers. With her substantial and influential contribution to the literature, Rovee-Collier clearly rose to this challenge. Throughout her career, Rovee-Collier was engaged in debates about appropriate techniques for studying infant behavior and inferring mental development. For example, Rovee-Collier (2001) summarizes many examples of studies in which different procedures like the looking preference procedure and the conjugate reinforcement mobile procedure led to different results (e.g., Gross, Hayne, Herbert, & Sowerby, 2002; Merriman, Rovee-Collier, & Wilk, 1997). Such discrepancies indicate the limitations of making strong conclusions about development from studies using a single experimental technique and underscore the importance of using a variety of procedures to obtain a comprehensive and clear understanding of infants' knowledge about people and objects in their environment.

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REFERENCES

- Acerra F, Burnod Y, & de Schonen S (2002). Modelling aspects of face processing in early infancy. *Developmental Science*, 5, 98–117.
- Anzures G, Quinn PC, Pascalis O, Slater AM, Tanaka JW, & Lee K (2013). Developmental origins of the other-race effect. *Current Directions in Psychological Science*, 22, 173–178. [PubMed: 24049246]
- Anzures G, Wheeler A, Quinn PC, Pascalis O, Slater AM, Heron- Delaney M, ... Lee K. (2012). Brief daily exposures to Asian females reverses perceptual narrowing for Asian faces in Caucasian infants. *Journal of Experimental Child Psychology*, 112, 484–495. [PubMed: 22625845]
- Baillargeon R (2004). Infants' physical world. *Current Directions in Psychological Science*, 13, 89–94.
- Baillargeon R, Li J, Weiting N, & Yuan S (2009). An account of infants' physical reasoning In Needham A, & Woodward A (Eds.), *Learning and the infant mind* (pp. 66–116). New York, NY: Oxford University Press.
- Bartlett J, & Searcy J (1993). Inversion and configuration of faces. *Cognitive Psychology*, 25, 281–316. [PubMed: 8354050]
- Bertin E, & Bhatt RS (2004). The Thatcher illusion and face processing in infancy. *Developmental Science*, 7, 431–436. [PubMed: 15484591]
- Bhatt RS, Bertin E, Hayden A, & Reed A (2005). Face processing in infancy: Developmental changes in the use of different kinds of relational information. *Child Development*, 76, 169–181. [PubMed: 15693765]
- Bhatt RS, Hayden A, Reed A, Bertin E, & Joseph JE (2006). Infants' perception of information along object boundaries: Concavities versus convexities. *Journal of Experimental Child Psychology*, 94, 91–113. [PubMed: 16516223]
- Bhatt RS, & Quinn PC (2011). How does learning impact development in infancy? The case of perceptual organization. *Infancy*, 16, 2–38. [PubMed: 21572570]
- Carey S, De Schonen S, & Ellis HD (1992). Becoming a face expert. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 335, 95–103.
- Carey S, & Diamond R (1994). Are faces perceived as configurations more by adults than by children? *Visual Cognition*, 1, 253–274.
- Cassia VM, Turati C, & Schwarzer G (2011). Sensitivity to spacing changes in faces and non-face objects in preschool-aged children and adults. *Journal of Experimental Child Psychology*, 109, 454–467. [PubMed: 21477815]
- Cohen LB (2004). Uses and misuses of habituation and related preference paradigms. *Infant and Child Development*, 13, 349–352.
- Cohen LB (2010). A bottom-up approach to infant perception and cognition: A summary of evidence and discussion of issues In Johnson SP (Ed.), *Neoconstructivism: The new science of cognitive development* (pp. 335–346). New York, NY: Oxford University Press.
- Collishaw SM, & Hole GJ (2000). Featural and configurational processes in the recognition of faces of different familiarity. *Perception*, 29, 893–910. [PubMed: 11145082]
- Farkas LG (1994). *Anthropometry of the head and face in medicine* (2nd ed.). New York, NY: Elsevier.
- Fiser J (2009). Perceptual learning and representational learning in humans and animals. *Learning and Behavior*, 37, 141–153. [PubMed: 19380891]
- Fiser J, & Aslin RN (2002). Statistical learning of new visual feature combinations by infants. *Proceedings of the National Academy of Sciences*, 99, 15822–15826.
- Freire A, Lee K, & Symons LA (2000). The face-inversion effect as a deficit in the encoding of configural information: Direct evidence. *Perception*, 29, 159–170. [PubMed: 10820599]
- Gross J, Hayne H, Herbert J, & Sowerby P (2002). Measuring infant memory: Does the ruler matter? *Developmental Psychobiology*, 40, 183–192. [PubMed: 11857332]
- Hayden A, Bhatt RS, Joseph JE, & Tanaka JW (2007). The other-race effect in infancy: Evidence using a morphing technique. *Infancy*, 12, 95–104.
- Hayden A, Bhatt RS, Kangas A, Zieber N, & Joseph JE (2012). Race- based perceptual asymmetry in face processing is evident early in life. *Infancy*, 17, 578–590.

- Hayden A, Bhatt RS, Zieber N, & Kangas A (2009). Race-based perceptual asymmetries underlying face processing in infancy. *Psychonomic Bulletin and Review*, 16, 270–275.
- Hayden A, Bhatt RS, Reed A, Corbly CR, & Joseph JE (2007). The development of expert face processing: Are infants sensitive to normal differences in second-order relational information? *Journal of Experimental Child Psychology*, 97, 85–98. [PubMed: 17339043]
- Heron-Delaney M, Anzures G, Herbert JS, Quinn PC, Slater AM, Tanaka JW, ... Pascalis O. (2011). Perceptual training prevents the emergence of the other race effect during infancy. *PLoS ONE*, 6, e19858. [PubMed: 21625638]
- Hunter MA, & Ames EW (1988). A multifactor model of infant preferences for novel and familiar stimuli. *Advances in Infancy Research*, 5, 69–95.
- Johnson MH (2011). Face perception: A developmental perspective In Calder AJ, Rhodes G, Johnson MH, & Haxby JV (Eds.), *The Oxford handbook of face perception* (pp. 3–14). Oxford, UK: Oxford University Press.
- Johnson SP (2009). The role of learning in cognitive development: Challenges and prospects In Needham A, & Woodward A (Eds.), *Learning and the infant mind* (pp. 286–295). New York, NY: Oxford University Press.
- Johnson SP, Fernandes KJ, Frank MC, Kirkham NZ, Marcus GF, Rabagliati H, & Slemmer JA (2009). Abstract rule learning for visual sequences in 8- and 11-month-olds. *Infancy*, 14, 2–18. [PubMed: 19283080]
- Johnson SP, & Shuwairi SM (2009). Learning and memory facilitate predictive tracking in 4-month-olds. *Journal of Experimental Child Psychology*, 102, 122–130. [PubMed: 18448114]
- Kelly DJ, Quinn PC, Slater AM, Lee K, Ge L, & Pascalis O (2007). The other-race effect develops during infancy evidence of perceptual narrowing. *Psychological Science*, 18, 1084–1089. [PubMed: 18031416]
- Kelly DJ, Quinn PC, Slater AM, Lee K, Gibson A, Smith M, ... Pascalis O. (2005). Three-month-olds, but not newborns, prefer own-race faces. *Developmental Science*, 8, F31–F36. [PubMed: 16246233]
- Leder H, Candrian G, Huber O, & Bruce V (2001). Configural features in the context of upright and inverted faces. *Perception*, 30, 73–84. [PubMed: 11257979]
- Le Grand R, Mondloch CJ, Maurer D, & Brent HP (2001). Neuroperception: Early visual experience and face processing. *Nature*, 410, 890–890. [PubMed: 11309606]
- Leder H, & Carbon CC (2006). Face-specific configural processing of relational information. *British Journal of Psychology*, 97, 19–29. [PubMed: 16464285]
- Maurer D, Le Grand R, & Mondloch CJ (2002). The many faces of configural processing. *Trends in Cognitive Sciences*, 6, 255–260. [PubMed: 12039607]
- Maurer D, Mondloch CJ, & Lewis TL (2007). Effects of early visual deprivation on perceptual and cognitive development. *Progress in Brain Research*, 164, 87–104. [PubMed: 17920427]
- McKone E (2010). Face and object recognition: How do they differ? In Coltheart V (Ed.), *Tutorials in visual cognition* (pp. 261–303). New York, NY: Psychology Press.
- McKone E, & Robbins R (2011). Are faces special In Calder AJ, Rhodes G, Johnson MH, & Haxby JV (Eds.), *Oxford handbook of face perception* (pp. 149–176). New York, NY: Oxford University Press.
- McKone E, & Yovel G (2009). Why does picture-plane inversion sometimes dissociate perception of features and spacing in faces, and sometimes not? Toward a new theory of holistic processing. *Psychonomic Bulletin & Review*, 16, 778–797. [PubMed: 19815781]
- Meltzoff AN, Kuhl PK, Movellan J, & Sejnowski TJ (2009). Foundations for a new science of learning. *Science*, 325, 284–288. [PubMed: 19608908]
- Merriman J, Rovee-Collier C, & Wilk A (1997). Exemplar spacing and infants' memory for category information. *Infant Behavior and Development*, 20, 219–232.
- Mondloch CJ, Le Grand R, & Maurer D (2002). Configural face processing develops more slowly than featural face processing. *Perception*, 31, 553–566. [PubMed: 12044096]
- Mondloch CJ, LeGrand R, & Maurer D (2010). Development of expertise in face recognition In Gauthier I, Tarr MJ, & Bub D (Eds.), *Perceptual expertise: Bridging in brain and behavior* (pp. 67–106). New York, NY: Oxford University Press.

- Mondloch CJ, Maurer D, & Ahola S (2006). Becoming a face expert. *Psychological Science*, 17, 930–934. [PubMed: 17176421]
- Mondloch CJ, & Thomson K (2008). Limitation in four-year-old children's sensitivity to the spacing among facial features. *Child Development*, 79, 1513–1523. [PubMed: 18826539]
- Moore DS, & Johnson SP (2011). Mental rotation of dynamic, three dimensional stimuli by 3-month-old infants. *Infancy*, 16, 435–445. [PubMed: 26312057]
- Morton J, & Johnson MH (1991). CONSPEC and CONLERN: A two- process theory of infant face recognition. *Psychological Review*, 98, 164–181. [PubMed: 2047512]
- Murray JE, Yong E, & Rhodes G (2000). Revisiting the perception of upside-down faces. *Psychological Science*, 11, 492–496. [PubMed: 11202495]
- Needham A (2000). Improvements in object exploration skills may facilitate the development of object segregation in early infancy. *Journal of Cognition and Development*, 1, 131–156.
- Needham A, & Baillargeon R (1998). Effects of prior experience on 4.5- month old infants' object segregation. *Infant Behavior and Development*, 21, 1–24.
- Needham A, Barrett T, & Peterman K (2002). A pick-me-up for infants' exploratory skills: Early simulated experiences reaching for objects using 'sticky mittens' enhances young infants' object exploration skills. *Infant Behavior and Development*, 25, 279–295.
- Nelson CA (2003). The development of face recognition reflects an experience-expectant and activity-dependent process In Pascalis O, & Slater A (Eds.), *The development of face processing in infancy and early childhood* (pp. 79–97). Hauppauge, NY: Nova Science.
- Oakes LM (2010). Using habituation of looking time to assess mental processes in infancy. *Journal of Cognition and Development*, 11, 255–268. [PubMed: 20730029]
- Pascalis O, de Hann M, & Nelson CA (2002). Is face processing species- specific during the first year of life? *Science*, 296, 1321–1323. [PubMed: 12016317]
- Pascalis O, & Kelly DJ (2009). The origins of face processing in humans: Phylogeny and ontogeny. *Perspectives on Psychological Science*, 4, 200–209. [PubMed: 26158945]
- Quinn PC, & Bhatt RS (2005). Learning perceptual organization in infancy. *Psychological Science*, 16, 511–515. [PubMed: 16008781]
- Quinn PC, & Tanaka JW (2009). Infants' processing of featural and configural information in the upper and lower halves of the face. *Infancy*, 14, 474–487.
- Quinn PC, Yahr J, Kuhn A, Slater AM, & Pascalis O (2002). Representation of the gender of human faces by infants: A preference for female. *Perception*, 31, 1109–1121. [PubMed: 12375875]
- Ramsey-Rennels JL, & Langlois JH (2006). Infants' differential processing of female and male faces. *Current Directions in Psychological Science*, 15, 59–62.
- Roder BJ, Bushnell EW, & Sasseville AM (2000). Infants' preferences for familiarity and novelty during the course of visual processing. *Infancy*, 1, 491–507.
- Robbins RA, Nishimura M, Mondloch CJ, Lewis TL, & Maurer D (2010). Deficits in sensitivity to spacing after early visual deprivation in humans: A comparison of human faces, monkey faces, and houses. *Developmental Psychobiology*, 52, 775–781. [PubMed: 20564328]
- Robbins RA, Shergill Y, Maurer D, & Lewis TL (2011). Development of sensitivity to spacing versus feature changes in pictures of houses: Evidence for slow development of a general spacing detection mechanism? *Journal of Experimental Child Psychology*, 109, 371–382. [PubMed: 21397248]
- Rossion B (2008). Picture-plane inversion leads to qualitative changes of face perception. *Acta Psychologica*, 128, 274–289. [PubMed: 18396260]
- Rovee-Collier C (1999). The development of infant memory. *Current Directions in Psychological Science*, 8, 80–85.
- Rovee-Collier C (2001). Information pickup by infants: What is it, and how can we tell? *Journal of Experimental Child Psychology*, 78, 35–49. [PubMed: 11161421]
- Rovee CK, & Rovee DT (1969). Conjugate reinforcement of infant exploratory behavior. *Journal of Experimental Child Psychology*, 8, 33–69. [PubMed: 5804591]
- Sangrigoli S, & de Schonen S (2004). Recognition of own-race and other- race faces by three-month-old infants. *Journal of Child Psychology and Psychiatry*, 45, 1219–1227. [PubMed: 15335342]

- Scott LS, & Monesson A (2009). The origin of biases in face perception. *Psychological Science*, 20, 676–680. [PubMed: 19422630]
- Simion F, Di Giorgio E, Leo I, & Bardi L (2011). The processing of social stimuli in early infancy: From faces to biological motion perception In Pascalis O, Atkinson J, & Innocenti G (Eds.), *Progress in brain research* (pp. 173–193). Burlington, VT: Academic Press.
- Thompson LA, Madrid V, Westbrook S, & Johnston V (2001). Infants attend to second-order relational properties of faces. *Psychonomic Bulletin & Review*, 8, 769–777. [PubMed: 11848598]
- Tottenham N, Tanaka JW, Leon AC, McCarry T, Nurse M, Hare TA, ... Nelson C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, 168, 242–249. [PubMed: 19564050]
- Valentine T (1988). Upside-down faces: A review of the effect of inversion upon face recognition. *British Journal of Psychology*, 79, 471–491. [PubMed: 3061544]
- Wagner SH, & Sakovits LJ (1986). A process analysis of infant visual and cross-modal recognition memory: Implications for an amodal code. *Advances in Infancy Research*, 4, 195–217.
- Walton GE, & Bower TGR (1993). Newborns form “prototypes” in less than 1 minute. *Psychological Science*, 4, 203–205.
- Wang SH, & Baillargeon R (2008). Can infants be “taught” to attend to a new physical variable in an event category? The case of height in covering events. *Cognitive Psychology*, 56, 284–326. [PubMed: 18177635]
- Wilcox T, & Chapa C (2004). Priming infants to attend to color and pattern information in an individuation task. *Cognition*, 90, 265–302. [PubMed: 14667698]
- Wilcox T, Smith T, & Woods R (2011). Priming infants to use pattern information in an object individuation task: The role of comparison. *Developmental Psychology*, 47, 886. [PubMed: 21142357]
- Wilcox T, & Woods R (2009). Experience primes infants to individuate objects: Illuminating learning mechanisms In Woodward A, & Needham A (Eds.), *Learning and the infant mind* (pp. 117–143). New York, NY: Oxford University Press.
- Woodward A, & Needham A (2009). *Learning and the infant mind*. New York: Oxford University Press.
- Yin RK (1969). Looking at upside-down faces. *Journal of Experimental Psychology*, 81, 141–145.
- Zieber N, Kangas A, Hock A, Hayden A, Collins R, Bada H, ... Bhatt RS. (2013). Perceptual specialization and configural face processing in infancy. *Journal of Experimental Child Psychology*, 116, 625–639. [PubMed: 23994509]
- Zieber N, Kangas A, Hock A, & Bhatt RS (2015). Body structure perception in infancy. *Infancy*, 20, 1–17.

FIGURE 1.

An example of the stimuli used in the familiarization and discrimination portions of Experiments 1–4. Infants were familiarized to an undistorted face (left) or its distorted version (right). Then they were tested for preference between the two faces (one of which would be familiar and the other novel). Note: The face used in this figure is just an illustration; the actual faces used in the experiments could not be shown due to publishing restrictions

FIGURE 2.

A sample flow chart of the procedure used in Experiments 2 and 3. During the procedure, the training, familiarization, and test faces were all of the same sex but different individuals. For instance, an infant might see female A and female B during training, but be familiarized and tested with female C. The faces used in this figure are for illustrative purpose only; the actual faces used in the experiments could not be shown due to publishing restrictions.

FIGURE 3.

Examples of the alternating faces used during priming in Experiment 4. Half of the infants were primed with inverted faces (top panel) and the other half were primed with featural changes (bottom panel). The familiarization and test phases were exactly the same as in Experiments 2 and 3. Note: The face used in this figure is just an illustration; the actual faces used in the experiments could not be shown due to publishing restrictions.

TABLE 1.

Time to accumulate 30 s of exposure and percent novelty preference scores in Experiments 1–4

	Nature of priming	N	Mean familiarization time (SE)	Mean preference (SE)	t-versus chance (50%)	P-value
Exp. 1	Upright no priming	12	30.44 (.959)	51.51 (2.25)	.67	.52
Exp. 2	Upleft spacing change	12	33.78 (1.97)	44.52 (2.38)	–2.31	.04 **
Exp. 3	Upleft spacing change	18	34.96 (2.58)	43.13 (3.32)	–2.07	.05 *
Exp. 4	Inverted spacing change	18	32.49 (1.13)	50.27 (2.54)	.11	.92
	Upleft feature change	18	30.41 (.172)	46.35 (4.09)	–.89	.39

Standard errors are presented in parentheses.

*P < .05, one-tailed

**P < .05, two-tailed