ijbd

International Journal of Behavioral Development
37(2) 148–153

DOI: 10.1177/0165025412471221
ijbd.sagepub.com
SAGE

Infant face preferences after binocular visual deprivation

Catherine J. Mondloch,[1] Terri L. Lewis,[2] Alex V. Levin,[3] and Daphne Maurer[2]

Abstract

Early visual deprivation impairs some, but not all, aspects of face perception. We investigated the possible developmental roots of later abnormalities by using a face detection task to test infants treated for bilateral congenital cataract within 1 hour of their first focused visual input. The seven patients were between 5 and 12 weeks old ($n = 3$) or older than 12 weeks ($n = 4$). Like newborns, but unlike visually normal age-matched controls, the patients looked preferentially toward *config* (three squares arranged as facial features) over its inverted version and none of the older patients preferred a positive-contrast face over the negative-contrast version. We conclude that postnatal changes in face perception are experience-dependent, and that interference with their typical development may contribute to later deficits in face processing.

Keywords

visual deprivation, face perception, face detection, role of visual experience, infants

The remarkable expertise of adults in recognizing the identity of individual faces is attributable to several underlying processes. First, adults have a remarkable ability to detect that a stimulus is a face based on first-order relations (two eyes above a nose and mouth). They do so rapidly even when there are no normal facial features (e.g., in paintings by Arcimbaldo in which an arrangement of fruit or vegetables forms the correct first-order relations for a face; Moscovitch, Winocur, & Behrmann, 1997), and when presented with two-tone Mooney face stimuli in which the perception of individual features has been compromised by transforming all luminance values to black or white (Kanwisher, Tong, & Nakayama, 1998; reviewed in Maurer, Le Grand, & Mondloch, 2002). Second, adults process faces holistically. When the top half of one face is combined with the bottom half of another face, adults make errors in identifying the top half, presumably because holistic processing integrates it with the novel bottom half, creating the impression of a novel identity (e.g., Hole, 1994; Young, Hellawell, & Hay, 1987; see Tanaka & Farah, 2003, for evidence of holistic processing in the part/whole effect). Finally, adults are exquisitely sensitive to differences among faces in the appearance of individual features and the spacing among them (e.g., Mondloch, Le Grand, & Maurer, 2002). They also appear to process faces using norm-based coding (reviewed in Jeffery et al., 2011), a process by which individual faces are compared to an average face.

In a series of studies, we have investigated the role of early visual experience in driving the development of normal face perception. We have tested patients who were deprived of early visual experience because they were born with dense and central cataracts in both eyes that blocked all patterned input from reaching the retina. Patterned visual input was delayed until later in infancy when the cataractous lenses were surgically removed and the eyes fitted with compensatory contact lenses. When tested later in childhood, patients treated for bilateral congenital cataract do not process faces holistically (Le Grand, Mondloch, Maurer, & Brent, 2004), although there may be recovery of holistic processing during adulthood (de Heering & Maurer, 2012). As adults, they are less sensitive than age-matched controls to differences among faces in the spacing of features (a configural cue called sensitivity to second-order relations—Le Grand, Mondloch, Maurer, & Brent, 2001; Robbins, Nishimura, Mondloch, Lewis, & Maurer, 2010) and, perhaps as a result, they make more errors than age-matched controls when asked to recognize faces across different points of view (de Heering & Maurer, 2012; Geldart, Mondloch, Maurer, De Schonen, & Brent, 2002). The deficit in sensitivity to feature spacing is face-specific: patients perform normally when discriminating both monkey faces and houses that differ only in feature spacing (Robbins et al., 2010). The patients' representation of faces also is not tuned normally to upright faces. Unlike visually-normal adults and 10-year-old children, they do not show opposing aftereffects for upright versus inverted faces (Robbins, Maurer, Hatry, Anzures, & Mondloch, 2012). Perhaps as a result, they are much worse than visually normal controls in recognizing famous faces or remembering ones that they have learned recently (de Heering & Maurer, 2012). In contrast, these patients develop normal sensitivity to differences among faces in the shape of individual features (Le Grand et al., 2001; Mondloch, Robbins, & Maurer, 2010) and the external contour (Mondloch, Le Grand, & Maurer, 2003). They develop normal accuracy in matching faces based on emotional expression, vowel being mouthed, and direction of eye gaze (Geldart et al., 2002), at least when the differences are large. They are

[1]Brock University, Canada
[2]McMaster University, Canada
[3]Thomas Jefferson University, USA

Corresponding author:
Catherine Mondloch, Brock University, 500 Glenridge Ave., St. Catharines, ON L2S 3A1, Canada.
Email: cmondloch@brocku.ca

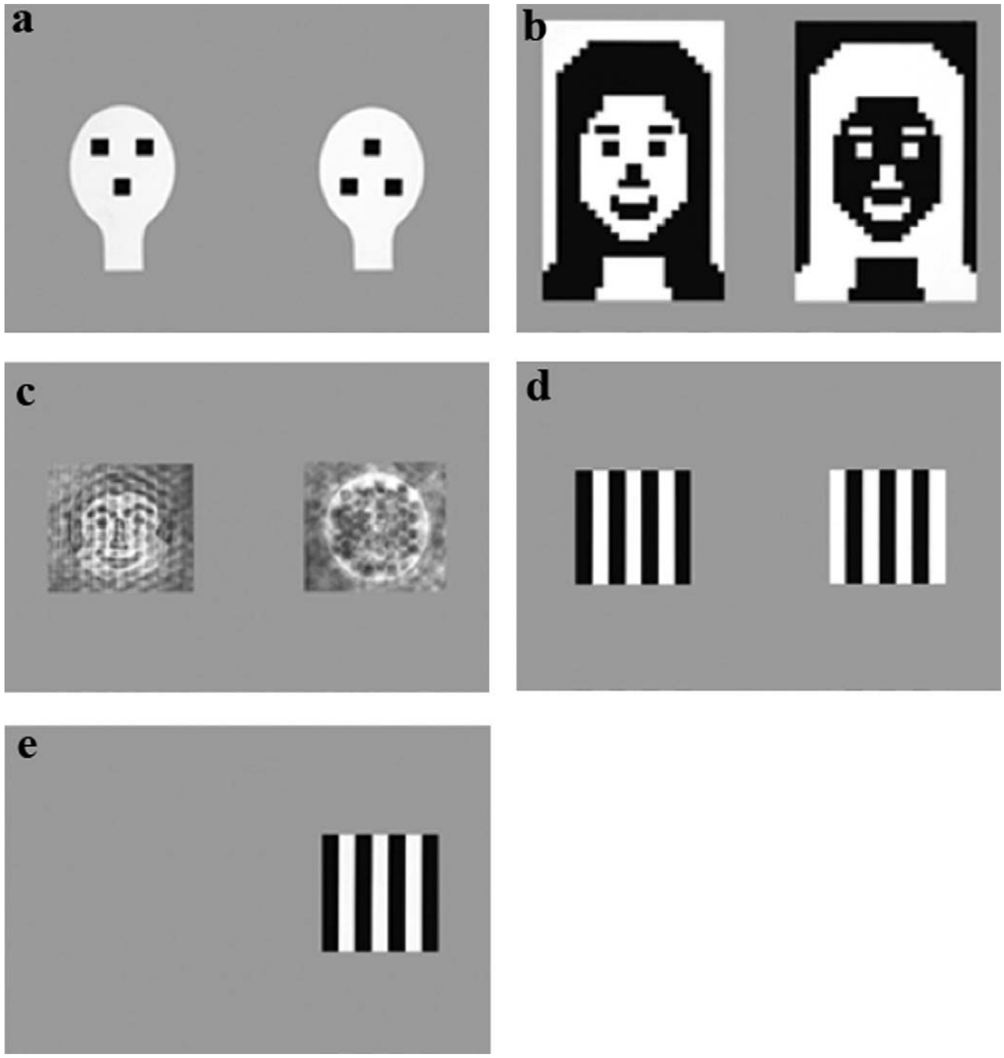

Figure 1. The three face/non-face stimulus pairs and two control stimuli.
Panel a shows *config* and its inversion (Johnson et al., 1991). Panel b shows the positive-contrast face and the negative-contrast face (Dannemiller & Stephens, 1988). Panel c shows the hybrid stimuli with phase of face/amplitude of lattice (left) and phase of lattice/amplitude of face (right). Patients were shown this pair but difficulty with observing even visually-normal infants precluded analysis. The control stimuli consisted of 2.5-cm-wide black-and-white stripes on both sides (Panel d) or on one side of centre (Panel e). There were five additional stimulus cards with the stimuli reversed left-to-right. Adapted from Mondloch et al. (1999).

also as good as controls at distinguishing between Mooney faces and scrambled images, although data from event-related potentials indicate that the underlying neural networks are abnormal, with patients showing a larger amplitude P100 and N170 than controls (Mondloch et al., in press). In the current study, we investigated the possible developmental roots of the later abnormalities by testing infant patients within 1 hour of their first focused visual input (i.e., within 1 hour of their receiving corrective contact lenses).

Newborns with normal eyes orient preferentially toward some face-like stimuli, such as a simple head outline with three squares arranged as facial features (a stimulus referred to as *config*) compared to the same head outline with the arrangement of features inverted (see Figure 1a) (e.g., Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991; Mondloch et al., 1999; Valenza, Simion, Macchi Cassia, & Umiltà, 1996). The preferences might be mediated sub-cortically (Johnson et al., 1991) and by low-level stimulus characteristics (Farroni et al., 2005; Kleiner & Banks, 1987; Macchi Cassia, Turati, & Simion, 2004; Macchi Cassia, Valenza, Simion, & Leo, 2008; Mondloch et al., 1999; Morton, Johnson, & Maurer, 1990). Regardless of its basis, these early preferences draw the attention of newborns to faces and may facilitate the development of more mature levels of face processing.

Infants' preferences change over the first few months after birth. By 5 to 6 weeks of age, infants no longer prefer *config* over its inverted version (Johnson & Morton, 1991; Mondloch et al., 1999), perhaps because *config* is such a degraded representation of a face, and they look preferentially at stimuli that have only the phase spectrum of a face when paired with stimuli that have only the amplitude spectrum (Kleiner & Banks, 1987; Mondloch et al., 1999; see Figure 1c). By 12 weeks of age, babies look preferentially toward positive-contrast schematic faces when paired with negative-contrast schematic faces (see Figure 1b), a preference that was absent at 6 weeks of age (Dannemiller & Stephens, 1988; Mondloch et al., 1999). These results suggest a gradual process of cortical specialization for face detection, likely influenced by the frequent exposure babies have to faces, interacting with their baby's attentional biases.

In the current study, we investigated whether infant patients show preferences for face-like stimuli like those of age-matched controls or experience-matched controls (i.e., newborns). The task we administered was modeled on the Teller acuity card procedure (Teller, McDonald, Preston, Sebris, & Dobson, 1986), in which a tester, unaware of the exact stimuli presented during each trial, can use any observed cues to decide whether or not an individual infant can see black and white stripes. In our adaptation of the Teller acuity card procedure, the tester's job for each trial was to determine, based only on the infant's looking behavior, whether the infant preferred the stimulus on the left or the right side of the card.

Because, in typically developing infants, the preference for *config* disappears at about 5 weeks of age (Johnson et al., 1991), we administered this face card task only to patients ($n = 7$) who received their first contact lenses, and thus their first patterned visual input, after that age. Four of these patients were at least 12 weeks of age, the age at which the preference for a positive contrast face emerges (Dannemiller & Stephens, 1988; Mondloch et al., 1999). If postnatal changes in this task are experience-dependent, then infants over 5 weeks old and tested within 1 hour of receiving their first patterned visual input (i.e., first contact lens wear) should look preferentially toward *config*, like newborn infants but unlike age-matched controls. Furthermore, patients who are at least 12 weeks of age at first visual input should show no preference for the positive contrast face, unlike age-matched controls who will have developed the preference sometime between 6 and 12 weeks of age. Patient results were compared to those of age-matched controls with normal vision.

Method

Participants

Seven infants treated for bilateral congenital cataract completed the face card task within 1 hour of receiving their first focused visual input, so that they were experience-matched to newborns (Mondloch et al., 1999). Each infant missed early normal input from faces because during early infancy they had cataracts that were so large and dense that they blocked all patterned input from reaching the retina. In six cases, the cataracts were diagnosed at the first eye exam (< 22 weeks); in one case partial cataracts were diagnosed at 2.7 weeks and total cataracts at 3.6 weeks (AS). The cataracts were removed surgically and then infants returned to the clinic 1 to 2 weeks later to receive rehabilitative contact lenses that, for the first time, allowed focused patterned visual input. All seven patients were at least 5 weeks old at the time of the contact lens fitting (*range* = 5.4 to 25.0 weeks) and thus were treated after visually-normal infants lose the preference for *config*. Four of the seven patients were at least 12 weeks old and thus were treated after visually-normal infants show a preference for the positive contrast face.

The performance of each patient on the day of treatment was compared to that of an age-matched control baby ($\pm$ 3 days) whose mothers had volunteered to participate in research at the time of the child's birth and to a group of experience-matched controls. Three of the patients were re-tested 3 to 6 weeks later, and two of these patients were tested again 11 weeks post-treatment. The follow-up data were also compared to the performance of both age-matched controls ($\pm$ 3 days) and to experience-matched controls. Experience-matched controls for the three test periods (immediately after, 3 to 6 weeks after, and 11 weeks after treatment, consisted of visually normal newborns, 6-week-olds and 12-week-olds, respectively ($n = 12$ per age group) whose data have been published previously (Mondloch et al., 1999). Each age-matched control infant was tested once.

Materials

The cards were 74.0 cm wide by 50.7 cm high. The tester watched the infant's eye movements through a 6 mm central observation hole. The background of the cards was gray, with a luminance equal to the mean luminance of that of the test stimuli. If the baby appeared to be distracted by extraneous stimuli, the cards were presented through a 74-cm $\times$ 50-cm porthole in a three-sided gray stage (1.75 m high by 2.30 m wide) to decrease unrelated peripheral stimuli.

The test stimuli consisted of five cards and their left-to-right reversals (see Figure 1) and were identical to those used by Mondloch et al. (1999). Four of the cards had two black-and-white photographs centered 19 cm (30 degrees of visual angle when viewed from 33 cm) to the left and right of centre. The remaining card had one black-and-white photograph centered 19 cm off to the side. One pair of cards contained *config* on one side and that same head outline with the arrangement of squares inverted on the other (Figure 1a). A second pair of cards contained a positive contrast schematic face on one side and a negative contrast schematic face on the other (Figure 1b). A third pair of cards contained a stimulus with the amplitude spectrum of a lattice but the phase spectrum of a face to one side and a stimulus with the phase spectrum of a face but the amplitude spectrum of a lattice to the other (Figure 1c). Data from this pair were not analysed.[1] The two control cards (see Figures 1d and 1e) had stripes on only one side or on both sides. They were designed to assess the validity of the test and to ensure that at each age tested, there was at least one card that should not elicit a visual preference (Figure 1d) and one card that should (Figure 1e). The test was designed so that an infant could be excluded from the final sample if the tester failed to detect the expected preference for either of the control cards.

The centres of the stimuli were matched to be 19 cm from the centre of the card. On the three cards with face-like stimuli, the size of the face portion (outer cheek to outer cheek) was matched (16 cm in width; 27.5 degrees when viewed from 33 cm). However, because the face stimuli varied in width beyond the face region across pairs (i.e., hair versus no hair), the distance from the centre of the card to the nearest edge of a face stimulus varied across face pairs (see Mondloch et al., 1999, for details).

Procedure

The procedure received ethics clearance from the Research Ethics Board at McMaster University and The Hospital for Sick Children, Toronto. We began by describing the study to the parent(s) and obtaining informed consent. The infant was placed in a position in which he or she was quiet and alert, with the eyes 33 cm from the stimuli. If a person was holding the baby and would otherwise be able to see the cards, the person either wore opaque glasses or kept his or her eyes closed during testing. Testing was binocular and all patients wore optical correction (contact lenses, supplemented

Table 1. Patient details.

Patient	Sex	Pre-op details	Diagnosis/ CL fitting (days)	Initial refractive error OD/OS (diopters)	Additional details	Config; Positive Contrast Immed	6 week	12 week
TA	F	no RR, no FF, no view of fundus, dense & total cataracts OU	39/50	+31.00/+26.50	Variable RET 15–20$^{\Delta}$	Conspec; No pref	Not tested	Not tested
NN	M	no RR, no FF, no view of fundus, dense & central, 6 mm nuclear cataracts OU	6/45	+29.00/+29.00	latent nystagmus OU	Conspec; No pref	Not tested	Not tested
TT	M	some FF, hazy view of fundus, dense & central, cataracts OU	96/113	+30.50/+31.00	Manifest nystagmus OU	Conspec; No pref	Not tested	Not tested
RC	F	no RR, no FF, no view of fundus, dense & central, 6 mm nuclear cataracts OU	107/121	+26.50/+26.00	Manifest nystagmus OU, mild microphthalmia OU; LET 40$^{\Delta}$	Inverted; No pref	No pref; Negative	Not tested
SB	M	no RR, no FF, no view of fundus, dense & central, nuclear cataracts OU	64/91	n/a	Manifest nystagmus OU, Variable ET 0–15$^{\Delta}$	No pref; No pref	No pref; No pref	No pref; Positive
BB	M	no RR, no FF, no view of fundus, dense & central, cataracts OU. OD: 6 mm total nuclear; OS: 7mm lamellar	150/176	+20.50/+20.50	Manifest nystagmus OU, RET 15$^{\Delta}$	Conspec; No pref	Not tested	Not tested
AS	F	no RR, no FF, no view of fundus, dense & central, 6 mm cataracts OU	25/38	+31.00/+31.50		No pref; No pref	No pref; No pref	No pref; Positive

Abbreviations: CL = contact lens; OD = right eye; OS = left eye; OU = both eyes; RR = red reflex; FF = fix and follow; RET = right esotropia; LET = left esotropia. Δ = prism dioptres where 2 prism dioptres = 1 deg of visual angle.
Visual preference indicated for Config vs. Inverted; Positive contrast vs. Negative contrast.

by an add, if needed) suitable for the testing distance of 33 cm. The tester first presented an anchor card that had only wide stripes on one side several times to be sure that the baby chose the stripes whether they were on the left or right. For the remaining ten cards, the tester knew only that the cards were arranged in pairs, so that each card was followed by its left-to-right reversal, but did not know what the stimuli were.

Visual preferences were determined subjectively using any behavioral indicators, but primarily direction of first look and duration of looking. The tester showed the baby the first card of a pair as many times as necessary to form a hypothesis about whether the baby preferred the stimulus on the left, preferred the stimulus on the right, or had no preference. The tester then showed the baby the second card, with the stimuli reversed left-to-right, to confirm the hypothesis and retested each card as many times as necessary to reach a decision for that pair. Before deciding that an infant had no preference with a particular pair of stimuli, the tester returned to the anchor card to verify that the baby still looked toward the side with the stripes.

Results

Immediate outcome

The procedure was valid: for every patient and every age-matched control, the tester came to the expected conclusion on control cards (i.e., the tester decided that the infants had no preference for the pair shown in Figure 1d and chose the side with the stripes for the pair shown in Figure 1e). On the day the patients first received focused patterned visual input (the day of first contact lens insertion), patient preferences resembled those of newborns (experience-matched infants), not age-matched controls. Four of the seven patients (57%) showed a preference for *config*, like 75% of the newborns we had tested previously. In contrast, no age-matched controls showed a preference for *config*. One patient showed a preference for the inverted version (like one of the original newborns) and two patients showed no preference, a pattern also seen occasionally in newborns. Like newborns, none of the four patients who were at least 12 weeks old at the time of treatment showed a preference for the positive contrast face whereas every age-matched control did so. Data for individual patients are shown in Table 1.

Follow-up

Three patients were tested after 3 to 6 weeks of contact lens rehabilitation. They performed like experience-matched controls (6-week-old infants with a normal visual history, Mondloch et al., 1999). None of the patients showed a preference for *config* (a preference that disappears by 5 to 6 weeks of age), and the two patients who had been at least 12 weeks old at the time of initial contact lens wear still failed to show a preference for the positive contrast face (a preference that emerges between 6 and 12 weeks of age). When tested 11 weeks post-treatment, both of these patients showed a preference for the positive-contrast face.

Discussion

The results are consistent with the hypothesis that post-natal changes in face detection require visual experience. Four of the seven infant patients tested within 1 hour of receiving their first patterned visual input looked preferentially toward *config* relative to its inverted version despite being at least 5 weeks old at the time. This preference is observed in normal newborns, but disappears by 5 to 6 weeks of age in infants with a normal visual history (Johnson et al., 1991; Mondloch et al., 1999; control group). None of the patients retested after 3–6 weeks of visual experience still showed this preference. Similarly, not one of the four infant patients who were at least 12 weeks old at the time of treatment looked preferentially toward the positive-contrast face, a preference that is robust by 12 weeks in visually-normal infants (Dannemiller & Stephens, 1988; Mondloch et al., 1999) and that was shown by every age-matched control infant. This preference was still not evident in any of the three patients retested after 3–6 weeks of visual experience but was evident in the two patients whom we were able to retest after 12 weeks of visual experience. These patterns are not likely to reflect post-treatment changes in acuity because, unlike the results for face preferences, over the same period, acuity recovers at rates faster than normal (Maurer, Lewis, Brent, & Levin, 1999). Moreover, poor acuity would be unlikely to affect either the preference for *config* and its inversion, because they have the same elements in different arrangements, nor the preference for a positive contrast face over a negative contrast face with exactly the same elements. Although our sample size was small, especially at follow-up tests, our findings suggest that postnatal changes in sensitivity to first-order relations in infants with normal eyes are driven by visual input.

Our results complement those of the only other study that has addressed the influence of experience on postnatal changes in face preferences. Sugita (2008) raised monkeys in a visually-rich environment but deprived them of experience with faces (caregivers wore hoods) from birth for a period of 6 to 24 months. At the end of the deprivation period, the monkeys looked preferentially toward both human and monkey faces compared to objects but showed no preference when presented with a monkey face paired with a human face. After one month of experience with human faces ($n = 6$) or monkey faces ($n = 4$), the deprived monkeys showed a visual preference and better discrimination for the species to which they had been exposed. Thus, as in our patients, postnatal refinements were driven by experience.

The results are consistent with the hypothesis that the development of face perception is an experience-dependent process. Like earlier findings for visual acuity (Maurer et al., 1999), at the time of treatment, patient preferences for face-like stimuli resemble those of normal newborns. After the onset of visual experience, however, the two aspects of vision improve at very different rates. Visual acuity improves at an accelerated rate such that within 1 hour of visual input, patients show improvement equivalent to that seen in typical infants over a period of 6 weeks (Maurer et al., 1999). In contrast, our study suggests that postnatal changes in face preferences likely proceed at a normal, albeit delayed, pace. Recovery from this initial deficit appears to allow some aspects of face perception (e.g., face detection, sensitivity to features) to reach normal levels (Le Grand et al., 2001; Geldart et al., 2002; Mondloch et al., 2003; Mondloch et al., 2010; Mondloch et al., in press). Nonetheless, the neural mechanisms underlying face detection (Mondloch et al., in press) and other aspects of face perception (e.g., sensitivity to spacing, holistic processing, norm-based coding; Le Grand et al., 2001; Geldart al., 2002; Le Grand et al., 2004; Robbins et al., 2010; Robbins et al., 2012; de Heering & Maurer, 2012) fail to develop normally, even when treatment occurs as early as 1–3 months of age—failures that the current study suggests may have their roots in the delay of normal post-natal changes in face detection.

Funding

This research was funded by grants from the Social Sciences and Humanities Research Council of Canada (DM, CJM) and the Canadian Institutes for Health Research (DM & TLL).

Note

1. We administered this pair of cards to each participant so that the set of stimuli would be identical to those used in our earlier work with visually normal infants (Mondloch et al., 1999). We are not reporting data for this pair of cards because consistent preferences were difficult to measure in age-matched controls.

References

Dannemiller, J. L., & Stephens, B. R. (1988). A critical test of infant pattern preference models. *Child Development*, *59*(1), 210–216.

de Heering, A., & Maurer, D. (2012). Face memory deficits in patients deprived of visual input by bilateral congenital cataracts. *Developmental Psychobiology.* Advance online publication. doi: 10.1002/dev.21094.

Farroni, T., Johnson, M. H., Menon, E., Zulian, L., Faraguna, D., & Csibra, G. (2005). Newborns' preference for face-relevant stimuli: Effects of contrast polarity. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(47), 17245–17250.

Geldart, S., Mondloch, C. J., Maurer, D., De Schonen, S., & Brent, H. P. (2002). The effect of early visual deprivation on the development of face processing. *Developmental Science*, *5*(4), 490–501.

Goren, C. C., Sarty, M., & Wu, P. Y. K. (1975). Visual following and pattern discrimination of face-like stimuli by newborn infants. *Pediatrics*, *56*(4), 544–549.

Hole, G. J. (1994). Configurational factors in the perception of unfamiliar faces. *Perception*, *23*(1), 65–74.

Jeffery, L., Rhodes, G., McKone, E., Pellicano, E., Crookes, K., & Taylor, E. (2011). Distinguishing norm-based from exemplar-based coding of identity in children: Evidence from face identity aftereffects. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(6), 1824–1840.

Johnson, M., & Morton, J. (1991). *Biology and cognitive development: The case of face recognition*. Oxford, UK: Basil Blackwell.

Johnson, M., Dziurawiec, S., Ellis, H., & Morton, J. (1991). Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition*, *40*(1–2), 1–19.

Kanwisher, N., Tong, F., & Nakayama, K. (1998). The effect of face inversion on the human fusiform face area. *Cognition*, *68*(1), B1–B11.

Kleiner, K. A., & Banks, M. S. (1987). Stimulus energy does not account for 2-month-olds' face preferences. *Journal of Experimental Psychology: Human Perception and Performance*, *13*(4), 594–600.

Le Grand, R., Mondloch, C. J., Maurer, D., & Brent, H. P. (2001). Neuroperception: Early visual experience and face processing. *Nature*, *410*(6831), 890.

Le Grand, R., Mondloch, C. J., Maurer, D., & Brent, H. P. (2004). Impairment in holistic face processing following early visual deprivation. *Psychological Science*, *15*(11), 762–768.

Macchi Cassia, V., Turati, C., & Simion, F. (2004). Can a nonspecific bias toward top-heavy patterns explain newborns' face preference? *Psychological Science*, *15*(6), 379–383.

Macchi Cassia, V., Valenza, E., Simion, F., & Leo, I. (2008). Congruency as a nonspecific perceptual property contributing to newborns' face preference. *Child Development*, *79*(4), 807–820.

Maurer, D., Le Grand, R. L., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in Cognitive Sciences*, *6*(6), 255–260.

Maurer, D., Lewis, T. L., Brent, H. P., & Levin, A. V. (1999). Rapid improvement in the acuity of infants after visual input. *Science*, *286*(5437), 108–110.

Mondloch, C. J., Le Grand, R., & Maurer, D. (2002). Configural face processing develops more slowly than featural face processing. *Perception*, *31*(5), 553–566.

Mondloch, C. J., Le Grand, R., & Maurer, D. (2003). Early visual experience is necessary for the development of some–but not all-aspects of face processing. In O. P. A. Slater (Ed.), *The development of face processing in infancy and early childhood: Current perspectives* (pp. 99–117). New York, NY: Nova Science Publishers.

Mondloch, C. J., Lewis, T.L., Budreau, D. R., Maurer, D., Dannemiller, J. L., Stephens, B. R., & Kleiner-Gathercoal, K. A. (1999). Face perception during early infancy. *Psychological Science*, *10*(5), 419–422.

Mondloch, C. J., Robbins, R., & Maurer, D. (2010). Discrimination of facial features by adults, 10-year-olds, and cataract-reversal patients. *Perception*, *39*(2), 184–194.

Mondloch, C.J., Segalowitz, S.J., Lewis, T.L.L., Dywan, J., Le Grand, R., & Maurer, D. (in press). The effect of early visual deprivation on the development of face detection and its neural correlates. *Developmental Science*.

Morton, J., Johnson, M., & Maurer, D. (1990). On the reasons for newborns' responses to faces. *Infant Behavior and Development*, *13*(1), 99–103.

Moscovitch, M., Winocur, G., & Behrmann, M. (1997). What is special about face recognition? Nineteen experiments on a person with visual object agnosia and dyslexia but normal face recognition. *Journal of Cognitive Neuroscience*, *9*(5), 555–604.

Robbins, R. A., Nishimura, M., Mondloch, C. J., Lewis, T. L., & 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*(8), 775–781.

Robbins, R. A., Maurer, D., Hatry, A., Anzures, A., & Mondloch, C. J. (2013). Effects of normal and abnormal visual experience on the development of opposing aftereffects for upright and inverted faces. *Developmental Science*, *15*, 194–203.

Sugita, Y. (2008). Face perception in monkeys reared with no exposure to faces. *Proceedings of the National Academy of Sciences*, *105*, 394–398.

Tanaka, J. W., & Farah, M. J. (2003). The holistic representation of faces. In M. A. Peterson & G. Rhodes (Eds.), *Perception of faces, objects, and scenes: Analytic and holistic processing* (pp. 53–74). Oxford, UK: Oxford University Press.

Teller, D. Y., McDonald, M. A., Preston, K., Sebris, S. L., & Dobson, V. (1986). Assessment of visual acuity in infants and children: The acuity card procedure. *Developmental Medicine & Child Neurology*, *28*(6), 779–789.

Valenza, E., Simion, F., Macchi Cassia, V. M., & Umiltà, C. (1996). Face preference at birth. *Journal of Experimental Psychology: Human Perception and Performance*, *22*(4), 892–903.

Young, A. W., Hellawell, D., & Hay, D. C. (1987). Configurational information in face perception. *Perception*, *16*, 747–759.