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Chapter 8

EARLY VISUAL EXPERIENCE IS NECESSARY FOR THE DEVELOPMENT OF SOME–BUT NOT ALL–ASPECTS OF FACE PROCESSING

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INTRODUCTION

Human faces are prevalent in the young infant's environment and from birth the infant orients toward them (Goren, Sarty, & Wu, 1975; Johnson et al., 1991; Mondloch et al., 1999; Valenza, Simion, Macchi Cassia, & Umiltà, 1996). This tendency ensures that the developing cortex will receive frequent exposure to faces during the first few weeks of life. We have been investigating the role of early visual experience in the development of adult expertise (Bahrick, Bahrick, & Wittlinger, 1975; see Bruce & Young, 1998 for a review) by testing patients who were deprived of early visual input due to congenital cataract. Our strategy has been to determine whether early visual deprivation causes permanent damage by testing the patients' face processing skills several (9 to 29) years after treatment. We have focused on three components of face processing: face detection, holistic processing (gluing the features together into a Gestalt), and the identification of individual faces (see Maurer, Le Grand, & Mondloch, 2002 for a review).

OUR PATIENT POPULATION

Our study population consists of children and adults who were treated for congenital cataract. A cataract is an opacity of the lens of the eye that, in the patients we selected for study, was sufficiently large and dense to block all patterned input from reaching the retina. We assumed that any child who had dense central cataracts diagnosed on their first eye exam

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and before 6 months of age had been deprived from birth because it would be unusual to have dense cataracts develop rapidly between birth and 6 months. Consequently, we defined the duration of deprivation as the period extending from birth until the age at which the infant received compensatory contact lenses, following surgery to remove the cataract (for additional details on inclusion criteria see Ellemberg, Lewis, Maurer, Liu, & Brent, 1999).

Patients were tested binocularly in all studies reported here. When necessary, patients wore an additional optical correction to focus the eyes at the testing distance. Patients vary in the duration of deprivation and in final visual acuity, and so for each study we determined whether the size of any deficit was correlated with either of these variables.

To validate our measures of face processing, we presented each task to a group of visually normal adults prior to testing deprived patients. Patients' performance was compared to normative data or to that of a visually normal control group matched to the patient group on age, race, handedness and gender. The normative data are from right-handed subjects only, because some face processing skills are lateralized (e.g., De Renzi, Perani, Carlesimo, Silveri, & Fazio, 1994; Deruelle & de Schonen, 1998; Kanwisher, McDermott, & Chun, 1997; McCarthy et al., 1997; McCarthy, Puce, Belger, & Allison, 1999). They are also from Caucasian subjects viewing Caucasian faces so that the results would not be influenced by variability in participants' familiarity with other races (e.g., see O'Toole, Peterson, & Deffenbacher, 1996, for the "other race" effect).

FACE DETECTION

Face detection is facilitated by the fact that all faces share the same first-order relational features, with two eyes above a nose, which is above a mouth (Diamond & Carey, 1986). Adults have a remarkable ability to detect faces, even in the absence of normal facial features. They readily detect a face when presented with a painting by Arcimbaldo in which an arrangement of fruit or vegetables forms a face (Moscovitch, Winocur, & Behrman, 1997) or when presented with a two-tone Mooney face (see Figure 1), at least when the stimuli are upright (Kanwisher, Tong, & Nakayama, 1998).

Even newborns orient preferentially towards some face-like over non-face patterns (Goren, Sarty, & Wu, 1975; Johnson et al., 1991; Mondloch et al., 1999; Valenza, Simion, Macchi Cassia, & Umiltà, 1996)—a result which suggests that they are able to detect the first-order relational features of a face. Although there are a variety of explanations for newborns' preference (Kleiner, 1987; Morton & Johnson, 1991; Simion, Macchi Cassia, Turati, & Valenza, 2001), the result is that the developing cortex receives frequent exposure to faces during the first few weeks of life. Early exposure may be necessary for the increasing specificity of visual preferences over the first year of life. By 6 weeks of age, infants no longer prefer a simple head outline with three blobs in the correct location for facial features over the same head outline with the array of blobs inverted (Johnson et al., 1991; Mondloch et al., 1999). In addition, unlike newborns, 6-week-olds' preferences are influenced more by stimulus structure than stimulus visibility (Kleiner & Banks, 1987; Mondloch et al., 1999). By 12 weeks of age, infants look preferentially toward a positive contrast schematic face over a negative contrast face (Dannemiller & Stephens, 1988; Mondloch et al., 1999). Detection of the first-order relations of a face in Mooney stimuli emerges still later. Although 10-month-olds look preferentially toward Mooney faces over scrambled Mooney faces, 6-month-olds show this preference only following familiarization with the original version of the Mooney face being tested (Latour, Rousset, Deruelle, & de Schonen, 1999).

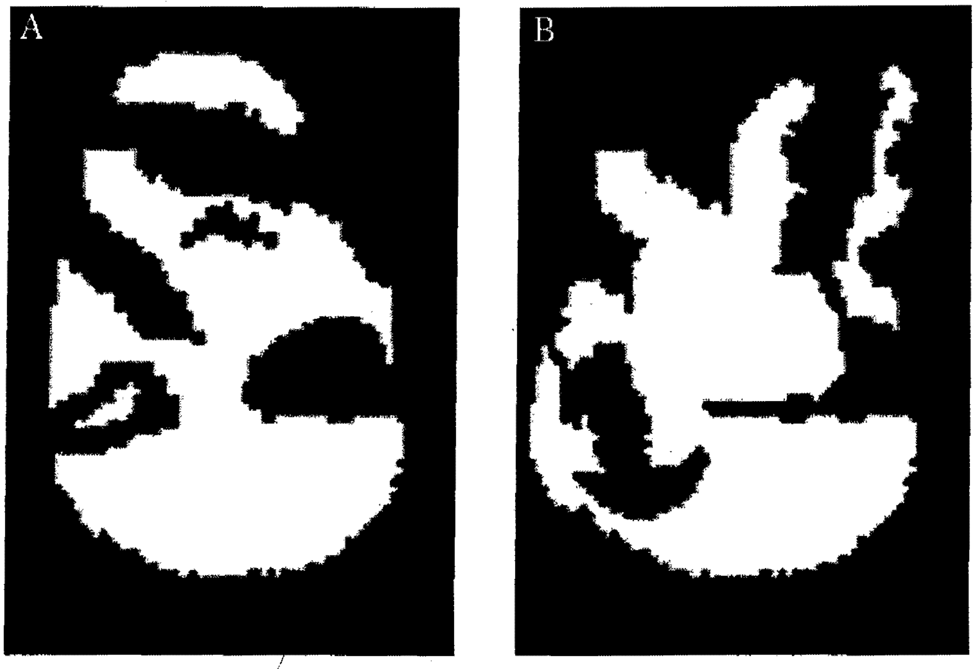

Figure 1. An inverted Mooney face (Panel A), and an inverted scrambled Mooney face (Panel B) are shown.

Despite the emergence and increasing specialization of face detection during the first year of life, face detection takes several years to mature. An electrophysiological marker of face detection is the ERP negative potential called the N170 (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2000; Rossion, Gauthier, Tarr, Despland, Bruyer, Linotte, & Crommilinck, 2000). Although a face-specific N170 emerges during infancy (de Haan, Pascalis, & Johnson, 2002), even at 14 years of age it is smaller in amplitude and longer in latency than that of adults (Taylor, Edmonds, McCarthy, & Allison, 2001; Taylor, McCarthy, Saliba, & Degiovanni, 1999). Evidence from adults suggests that the N170 may also be a marker for expertise. After extensive training with photographs of "greebles", adults demonstrate a face-like N170 for upright greebles (Rossion, Gauthier, Goffaux, Tarr, & Crommelinck, 2002), much as dog experts and bird experts do when shown stimuli from their category of expertise (Tanaka & Curan, 2001). The slow maturation of N170 for faces and the presence of an N170 following extensive training with non-face stimuli suggest slow maturation of expertise with faces. The goal of our research was to determine whether early visual experience is necessary for the later development of normal face detection.

Our Task

To measure sensitivity to face-like first order relations, we developed a behavioural task in which participants are presented with twelve Mooney faces and twelve scrambled Mooney faces, each for 100 msec (see Figure 1). The stimuli are presented in a random order and for each stimulus, participants use a joystick to indicate whether the stimulus is a face or a nonface. Visually normal adults' (N=24) accuracy was high (94%) when the stimuli were upright, a result that demonstrates adults' sensitivity to face-like first-order relations. When the stimuli were inverted, adults' accuracy decreased (82%; see Figure 2, panel A) and their reaction times increased (Le Grand, Mondloch, Maurer, de Schonen, & Brent, 2002). These results are consistent with previous studies showing that inverting Mooney faces disrupts face detection and reduces the N170 (Kanwisher et al., 1998; Rodriguez, George, Lachaux, Martinerie, Renault, & Varela, 1999).

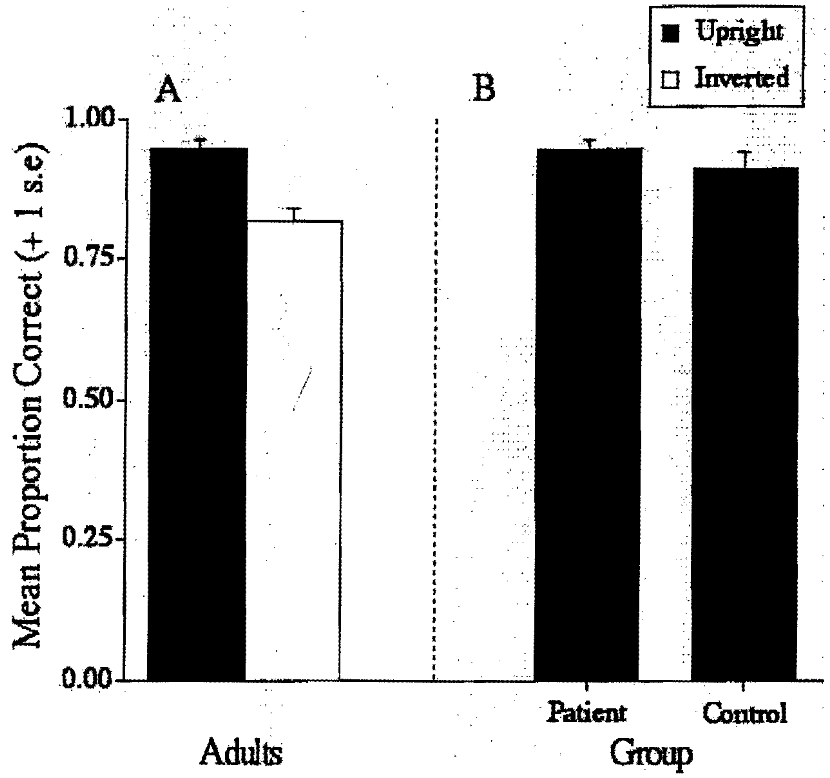

Figure 2. Mean accuracy (+1 s.e.) for visually normal adults when stimuli were presented upright versus inverted (Panel A). Mean accuracy (+1 s.e.) for patients and normal controls when stimuli were presented upright (Panel B).

Patients

To measure the effect of early visual deprivation on face detection, we tested patients (n=11) treated for bilateral cataract on the Mooney task (Le Grand, Mondloch, Maurer, de Schonen, & Brent, 2002) (see Table 1 for details on patients). Their results were compared to those of a visually normal control group (n=11). Patients were as accurate (M = 92%) and as fast (M = 824 msec) as the control subjects (M accuracy = 89%; M reaction time = 799) (ps > 0.10; see Figure 2, panel B). Patients' normal performance cannot be attributed to a ceiling effect: all but three subjects (2 patients, 1 control) made errors and reaction times are not constrained by ceiling effects.

Table 1. Patient

Study	Number of Patients	Number of Females, RH, Caucasian	Age in Years Mean (range)	Acuity in Better Eye Mean (range)	Duration of Deprivation in months Mean (range)
Face Detection	11	6, 10, 9	14.5 (9 - 20)	20/45 (20/25 - 20/80)	4 (2 - 6)
Holistic Processing	12	4, 12, 12	15 (9 - 23)	20/40 (20/32 - 20/63)	4.6 (3.2 - 6.2)
Identifying Faces - Bilaterally deprived	14	8, 13, 11	14 (9 - 21)	20/40 (20/25 - 20/80)	4.0 (2 - 6.2)
Identifying Faces - Left-eye deprived	10	8, 10, 10	17 (8 - 29)	20/20 (20/20 - 20/25)	6.6 (1.4 - 28.8)
Identifying Faces - Right-eye deprived	10	8, 10, 9	15 (9 - 23)	20/25 (20/16 - 20/32)	6.7 (1.9 - 16.1)

Our results suggest that the eventual development of normal sensitivity to first-order relations does not depend upon early visual input. We do not know, of course, whether the neural correlates of face detection by patients are the same as those found in visually normal individuals (Aguirre et al., 1999; Bentin et al., 1996; Haxby, et al., 2001; McCarthy et al., 1997; Rossion et al., 2000). However, our behavioural results are consistent with the hypothesis that patients' poor performance in other aspects of face processing (see below) result from a deficit in processing that occurs after a face is detected (Eimer, 2000).

Holistic Processing of Faces

When adults detect the first-order relations of a face, they tend to process the stimulus as a Gestalt, making it harder to process individual features. The most convincing demonstration is *the composite face effect.* Adults are slower and less accurate in recognizing the top half of one face presented in a composite with the bottom half of another face when the composite is upright and fused than when the composite is inverted or the two halves are offset laterally--manipulations that disrupt holistic processing (Figure 3). This phenomenon demonstrates that when upright faces are processed, the internal features are so strongly integrated that it becomes difficult to parse the face into isolated features, at least at short exposures that prevent feature-by-feature comparisons (Hole, 1994). The effect has been demonstrated both when adults are asked to identify the top half of a familiar face (Young, Hellawell, & Hay, 1987) and when they are asked to make same/different judgments about the top halves of two unfamiliar faces (Hole, 1994).

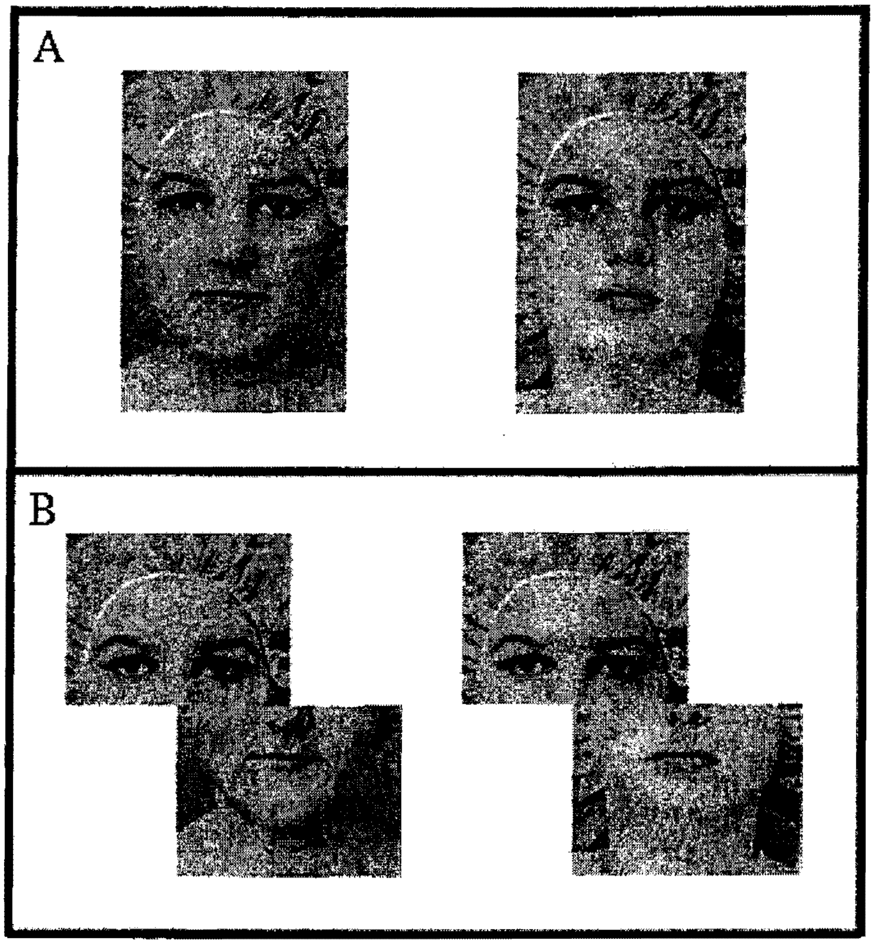

Figure 3. A pair of intact (Panel A) and misaligned (Panel B) composite faces; the top halves are the same and the bottom halves are different.

There is some evidence of holistic processing at 7 months of age (Cashon & Cohen, 2001). Following habituation to each of two faces, 7-month-olds dishabituate to both a completely novel face and a composite face comprised of the internal features of one familiar face and the external features of the other, indicating that they had 'glued together' the internal and external features of the original faces. Whether infants also process internal features holistically remains unknown. However, by 6 years of age (the youngest age tested), children show an adult-like composite face effect both for classmates and for faces they learned to recognize during an immediately preceding training period (Carey & Diamond, 1994).

Our Task

To measure holistic processing we created a modified version of the composite face task (Hole, 1994). Participants are presented with two composite faces in sequence, each for 200 msec., and use a joystick to indicate whether the top halves are the same or different. The bottom halves are different on every trial, making the task more difficult on 'same' trials when the faces are fused (i.e., holistic processing was engaged) than on 'same' trials when the faces are misaligned (i.e., when holistic processing is disrupted). Indeed, visually normal adults (n = 24) were significantly less accurate on fused same trials (M = 62.8%) than they were on misaligned same trials (M = 85.8%) (see Figure 4a). These results indicate that our version of the composite face task does measure holistic processing.

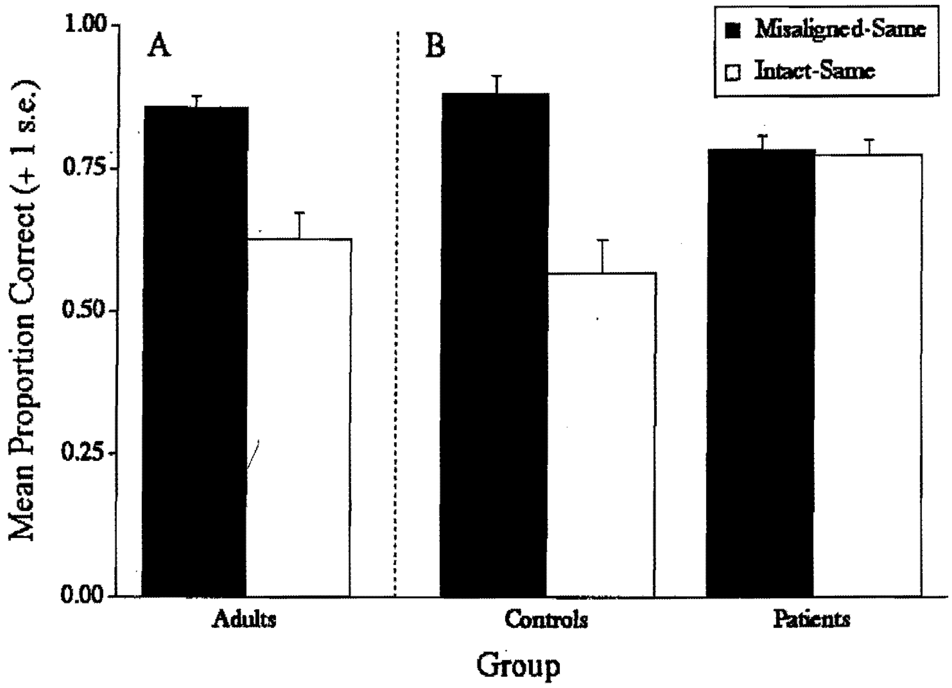

Figure 4. Mean accuracy on 'same' trials (+1 s.e.) for visually normal adults (Panel A) and for patients and normal controls (Panel B) on the composite face task.

Patients

To determine whether holistic processing develops normally in the absence of early visual experience we tested patients (n = 12) treated for bilateral congenital cataracts on our version of the composite face task (Le Grand, Mondloch, Maurer, & Brent, 2002) (see Table 1 for details on patients). Their results were compared to a visually normal control group. As expected, normal controls (n = 12) were much less accurate on misaligned same trials (M = 55%) than they were on fused same trials (M = 86%). In contrast, patients' accuracy did not differ (M = 76%) on the two trial types (see Figure 4b). Patients' reaction times were not longer on fused trials than they were on misaligned trials, nor were their reaction times longer than normals' (*ps* > .10). Patients' performance on this task was not correlated with either duration of deprivation or their visual acuity in the better eye (ps > .10). These results suggest that holistic processing does not develop normally in the absence of early visual experience.

These results are particularly striking because patients demonstrated a deficit in holistic processing by performing *more* accurately (M = 76%) than visually normal control subjects (M = 55%) on the fused same trials ($p < 0.01$).

IDENTIFYING FACES

Recognizing individual faces may be facilitated by cues such as hair style/colour and paraphernalia (e.g., glasses), but we have focused on three more reliable cues to facial identify: the shape of the external contour, the shape of individual features (e.g., eyes, mouth), and the spacing among those features (e.g., distance between the eyes). Several lines of research have demonstrated that when faces are upright, adults are able to identify faces using both featural information and second-order relations to identify faces (Freire, Lee, & Symons, 2000; Collishaw & Hole, 2000; see Maurer et al., 2002 for a review). When faces are inverted adults continue to be able to use featural information nearly as well, but are impaired in their ability to use second-order relations (Freire et al., 2000; Leder & Bruce, 2000; Rhodes, Brake, & Atkinson, 1993). For example, adults' face recognition is fairly accurate when faces either are blurred (disrupting sensitivity to the shape of individual features) or inverted (disrupting sensitivity to second-order relations), but not both (disrupting sensitivity to both cues simultaneously) (Collishaw & Hole, 2000).

Several studies have shown that children perform worse than adults on face recognition tasks (e.g., Carey et al., 1980)—even in matching tasks, which eliminate memory demands (Bruce et al., 2000). Children may perform worse than adults for several reasons: they are more easily fooled by paraphernalia (e.g., glasses, hats) (Carey & Diamond, 1977); they rely more than adults do on external contour (Campbell & Tuck, 1985; Campbell et al., 1995); and they are less sensitive to second-order relations (i.e., the spacing among features) (Freire & Lee, 2001; Mondloch, Le Grand, & Maurer, 2002a).

Our Task

To measure the ability to match facial identity based on different cues, we modified a single female face (called 'Jane') to create twelve new versions (called 'sisters')—four that differed in the shape of internal features (featural set), four that differed in the shape of the external contour (contour set) and four that differed in the spacing among internal features (spacing set) (Mondloch et al. 2002a) (Figure 5). Pairs of faces were presented sequentially and, for each pair, participants used a joystick to indicate whether the two faces were the same or different. Adults' accuracy exceeded 80% for all face sets (Figure 6). When the stimuli were inverted, there was a small (7-10%) decrease in accuracy for the featural and contour sets. In contrast, there was a large (20%) decrease in accuracy for the spacing set, as would be expected if the spacing set taps sensitivity to second-order relations more than the featural set and the contour set (see also Freire et al., 2000).

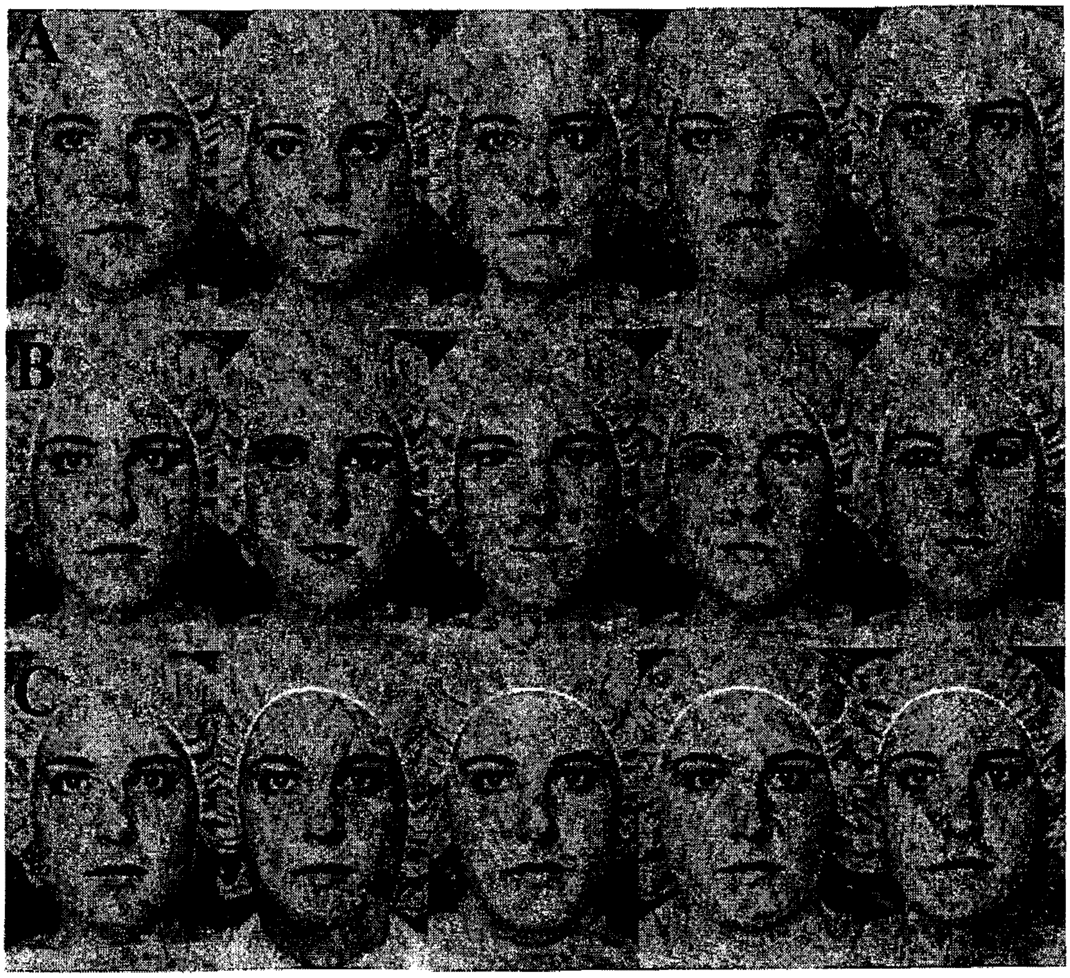

Figure 5. "Jane" is shown as the left-most face in each panel, along with her sisters from the spacing set (Panel A), the featural set (Panel B) and the external contour set (Panel C). Reprinted, by permission, from *Perception*, 2002, vol. 31, pp 553-566 (Pion Limited, London).

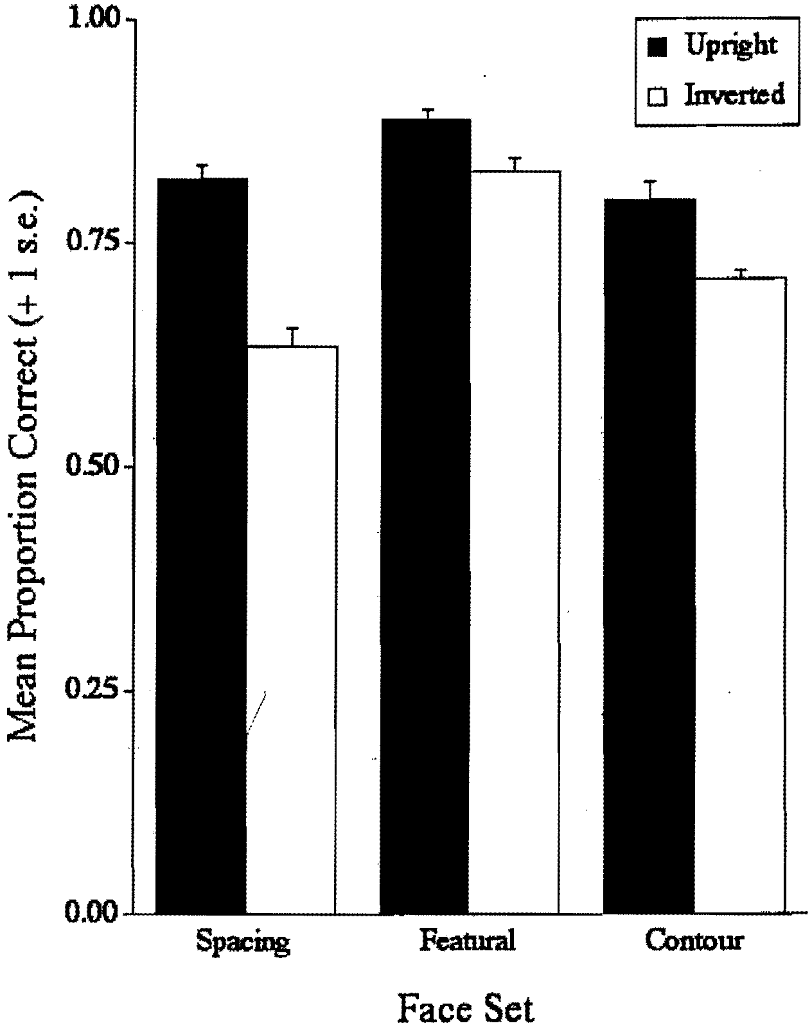

Figure 6. Mean accuracy (+ 1 s. e.) for visually normal adults when stimuli were presented upright and inverted on the "Jane" task.

We also showed that there is very little developmental change on the featural and external contour sets, a result that is consistent with previous studies showing that young children rely more than adults on external contour when recognizing familiar faces (Campbell & Tuck, 1995; Campbell et al., 1995). In contrast, every age group of children—even 14 year olds—make more errors than adults on the spacing set, a result showing especially slow maturation of sensitivity to second-order relations (Mondloch et al., 2002a,b). Although adults were equally accurate on the contour and spacing sets ($p > .10$), adultlike accuracy was achieved by age 6 for the contour set but not even by age 14 for the spacing set.

Patients

To assess the influence of early visual experience on the normal development of face recognition we tested 14 patients treated for bilateral congenital cataract (see Table 1). Each patients' accuracy score was translated into a standardized score based on normative data (see Figure 7). Patients performed normally on the featural and external contour sets, but were severely impaired on the spacing set and performed in the range of the lowest 2% of the normal population (see also Le Grand, Mondloch, Maurer, & Brent, 2001 for comparisons to a control group). Analyses of reaction times showed that their poor performance could not be attributed to speed-accuracy trade-offs. Performance was not related either to the duration of deprivation or visual acuity in the better eye ($\underline{p}$s > .10; Le Grand et al., 2001).

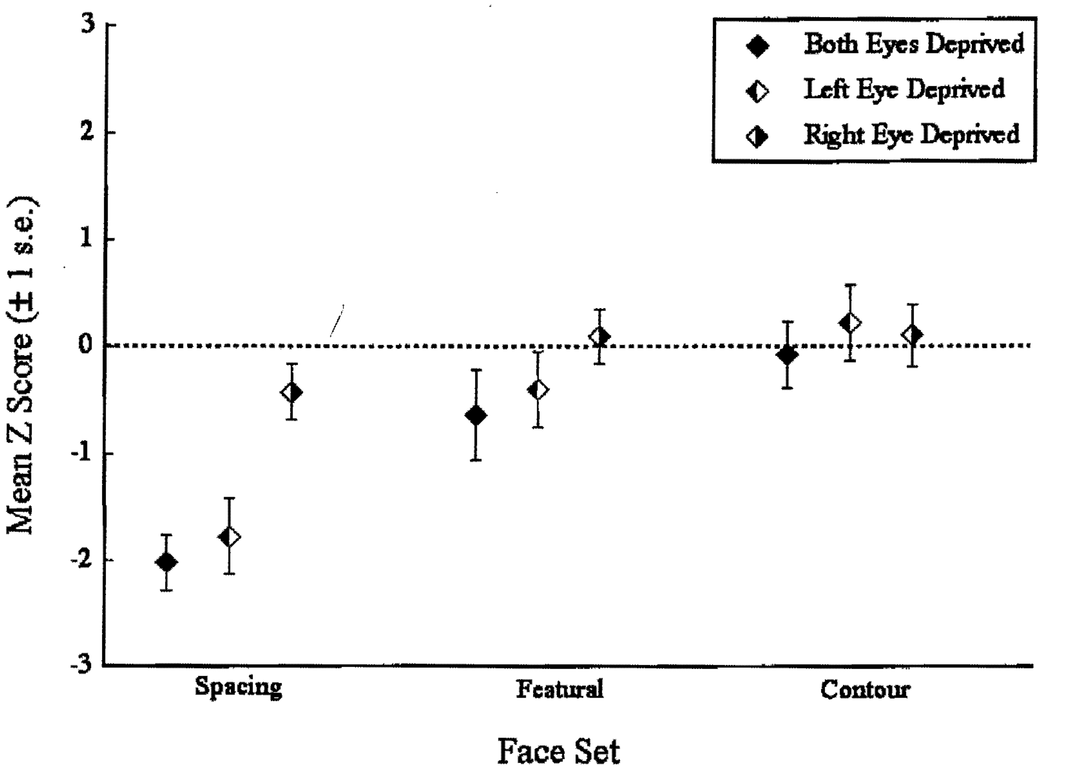

Figure 7. Mean standardized scores (± 1 s.e.) for the three face sets in the "Jane" task for patients treated for congenital cataract in both eyes, the left eye, or the right eye. Testing was binocular. (Note. N=10 for all groups; the mean for bilaterally deprived patients is based on the 10 patients with whom the unilaterally deprived patients were compared. See section called "The role of the right hemisphere".)

This pattern of performance suggests that, in the absence of visual input during early infancy, sensitivity to second-order relations fails to develop normally, and that as little as 2 months of deprivation is sufficient to cause the deficit. This pattern of results is especially interesting given our finding that sensitivity to second-order relations is particularly slow to develop in visually normal children (Mondloch et al., 2002a,b). Collectively, our results suggest that early visual experience is necessary to set up/maintain the neural architecture that, much later, will become specialized for processing the spacing among features.

The differential effects of early visual deprivation on sensitivity to first-order relations (i.e., face detection) and on sensitivity to second-order relations is consistent with evidence that they are reflected in different neural correlates (Liu, Harris, & Kanwisher, 2002) and that cortical damage can impair sensitivity to second-order relational processing without affecting face detection (Barton, Press, Keenan, O'Connor, 2002).

It is possible that patients' deficit in sensitivity to second-order relations is caused by deficits in holistic processing. Sensitivity to the spacing among features will be enhanced by integrating across large regions of the face; patients' deficits in holistic processing suggest that they fail to do so. Nonetheless, children as young as 6 years of age appear to process faces holistically (Carey & Diamond; 1994) but even 14-year-olds make more errors than adults on the spacing set (Mondloch et al., 2002a,b). Thus performance on tasks that measure sensitivity to spatial relations is somewhat independent of performance on tasks that measure holistic processing.

THE ROLE OF THE RIGHT HEMISPHERE

The right hemisphere appears to play a special role in face processing. Neuroimaging studies have shown that in adults, fMRI activity elicited by faces is often greater in the right hemisphere than the left hemisphere (Kanwisher, McDermott, & Chun, 1997; McCarthy et al., 1997; McCarthy, Puce, Belger, & Allison, 1999). Unilateral lesions restricted to these regions of the right hemisphere, but not the left hemisphere, can lead to severe impairment in face processing (prosopagnosia) (De Renzi, Perani, Carlesimo, Silveri, & Fazio, 1994), especially for tasks that require sensitivity to second-order relations (Barton et al., 2002). Furthermore, infants 4 to 9 months old learn to discriminate briefly presented faces and geometric patterns (e.g., a diamond comprised of circles) based on their local features when the stimuli are presented in the RVF/LH but fail to learn when the stimuli are in the LVF/RH (Deruelle & de Schonen, 1995; 1998). They learn to make discriminations based on the arrangement of the elements when the stimuli are presented in the LVF/RH but perform less well when they are in the RVF/LH. de Schonen and Mathivet (1989) proposed that the right hemisphere becomes specialized for the processing of information about spacing because regions of the temporal cortex that receive information about faces become functional earlier in the right hemisphere than do homologous regions in the left hemisphere. Young infants' poor visual acuity and contrast sensitivity limit encoding to information carried by lower spatial frequencies and, based on this input, the cortex—particularly the right hemisphere—begins to form stable networks that will eventually become specialized for configural processing of visual patterns and faces (de Schonen & Mathivet, 1989). Early binocular deprivation appears to prevent this network from stabalizing because, despite years of subsequent exposure to faces, sensitivity to second-order relations is abnormal (Le Grand et al., 2001).

To more directly investigate the contribution of early visual experience to the normal development of face processing by each hemisphere, we compared patients who were deprived of visual input primarily to either the left/right hemisphere due to a unilateral congenital cataract in either the right or left eye. During infancy, sensitivity to stimuli in the temporal visual field develops much faster than sensitivity to the nasal visual field (Lewis & Maurer, 1990). Visual input from the temporal visual field projects to the nasal hemi-retina and is transmitted to the contralateral cerebral hemisphere. In addition, the corpus callosum does not allow functional integration of visual information across the two hemispheres prior to 2 years of age (Liegeois, Bentejac, & de Schonen, 2000). Consequently, visual deprivation of one eye (e.g., left) results in relatively greater deprivation of the contralateral (i.e., right) hemisphere. Thus, to the extent that the effects of bilateral deprivation can be attributed to deprivation of early visual input to the right hemisphere, infants treated for unilateral cataract in the left eye should perform like patients treated for bilateral cataract (i.e., abnormally on the spacing set on the "Jane task", but normally on the featural and contour sets), whereas infants treated for unilateral cataract in the right eye should perform more like visually normal controls.

We compared performance (based on normative data) in patients treated for right-eye deprivation and patients treated for left-eye deprivation to patients we had tested previously who were treated for deprivation of both eyes ($n = 10$ per group; see Table 1) (Mondloch, Le Grand, Maurer, & Brent, 2001). All patients were tested binocularly, and thus patients treated for unilateral cataract were able to use their normal fellow eye. As expected based on the performance of bilaterally deprived patients, both groups of patients treated for unilateral congenital cataract performed normally on the featural set and on the contour set (see Figure 7). Patients treated for unilateral cataract in the right eye (greater deprivation of the left hemisphere) also performed normally on the spacing set. In contrast, patients treated for unilateral cataract in the left eye (greater deprivation of the right hemisphere) were severely impaired on the spacing set and performed no better than patients treated for bilateral congenital cataract on this set. Although performance for patients treated for unilateral cataract in the left eye was related to duration of deprivation ($r = -0.74$, $p < 0.01$), the correlation was nonsignificant ($p > .10$) when the patient with the longest period of deprivation was removed from the analysis. These findings suggest that early visual input to the right hemisphere is necessary for the development of normal sensitivity to second-order relations.

Practical Implications

Patients treated for bilateral congenital cataract or unilateral congenital cataract in the left eye are less sensitive than visually normal control subjects to second-order relations but are normal in their sensitivity to the shape of individual internal and external features. We investigated the implication of this pattern of performance in the real world by probing a number of face processing skills (Geldart, Mondloch, Maurer, de Schonen, & Brent, 2002). In each task, subjects were presented with a target face for 2 seconds, followed by 3 test faces. They were asked to indicate which of the three test faces matched the target face in: (1) identity, despite changes in emotional expression; (2) identity, despite changes in head orientation; (3) emotional expression, despite changes in identity; (4) vowel being mouthed, despite changes in identity; and (5) direction of eye gaze, despite changes in identity and head orientation.

Patients performed as well as visually normal control subjects on three of the five tasks: matching facial expression, lip reading, and direction of eye gaze—tasks that require processing small, individual features (e.g., the shape of the lips) or local relations (e.g., the direction of gaze). They performed worse than normal controls in matching faces' identity/changed head orientation ($p \leq .001$) (see Figure 8)—a task that likely taps sensitivity to spacing of features because the shape of individual features changes across head orientations, whereas the spacing among features remains relatively invariant. They also tended to be less accurate in matching faces identity/changes in facial expression (p=.067).

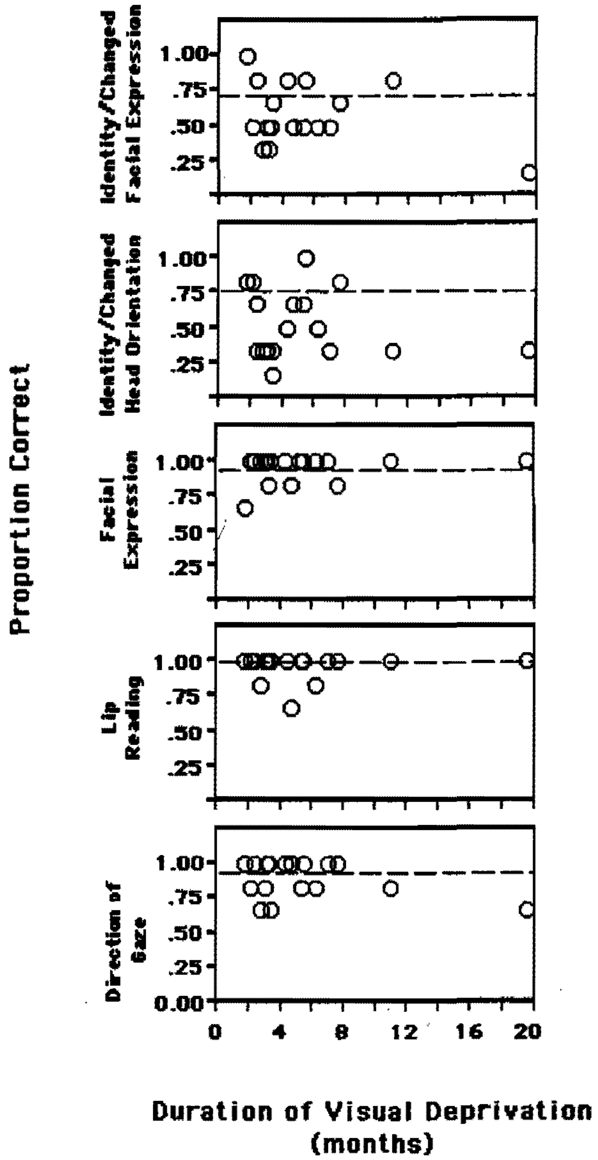

Figure 8. Accuracy scores for five tasks of face matching in patients with a history of early visual deprivation. Each dot represents accuracy for one patient plotted as a function of the duration of visual deprivation. For comparison, the mean accuracy from normal controls for each task is illustrated by a dotted line. Points on or near the line are within normal limits; points well below the line represent deficits. Chance performance is 0.33. Reprinted, by permission, from *Developmental Science*, 2002, vol. 5, pp. 490-501 (Blackwell Publishing, Oxford).

To evaluate the contribution of sensitivity to second-order relations to each of these tasks, we compared groups of adults tested with the stimuli upright or inverted (n=24 per group). Inversion disrupted performance on only one of the five tasks—matching facial identity despite changes in head orientation (unpublished data). Thus patients perform normally on tasks that tap sensitivity to individual features, but show deficits on tasks that tap sensitivity to second-order relations. Interestingly, like accuracy on the spacing set in the "Jane" task, we found in another study that matching identity despite changes in head orientation was the only one of the five tasks on which 10-year-olds were not as accurate as adults (unpublished data).

SUMMARY

Early visual experience is necessary for some, but not all, components of face processing. Several years after treatment for bilateral congenital cataracts, patients demonstrate normal sensitivity to face-like first-order relations and normal processing of internal features and of contour. In contrast, they failed to show evidence of holistic processing and they made more errors than normal controls on the tasks that required sensitivity to second-order relations. These results are consistent with models that postulate multiple components of face perception that may rely on different information-processing pathways (see Bruce & Young, 1986; 1998).

More specifically, early visual input to the right hemisphere is necessary for the development of normal sensitivity to second-order relations. Patients treated for unilateral congenital cataract in the left eye (greater deprivation of the right hemisphere) performed as poorly as patients treated for bilateral congenital cataract---despite being tested binocularly. These results are consistent with neuroimaging data (e.g., Kanwisher, McDermott, & Chun, 1997), studies of individuals treated for unilateral lesions (De Renzi, Perani, Carlesimo, Silveri, & Fazio, 1994), and studies of hemispheric specialization during early infancy (Deruelle & de Schonen, 1995, 1998), all of which suggest a special role for the right hemisphere in face processing. Consistent with de Schonen and Mathivet's (1989) theory, early visual input to the right hemisphere is necessary for setting up (or preserving) the neural architecture that will become specialized for processing the spacing among facial features.

Future studies with patients treated for congenital cataract will determine the extent to which their deficits are face specific. In addition, imaging studies are needed to determine whether they use the normal face processing networks, which were damaged by early deprivation, or--as is true for shape discrimination in binocularly deprived cats (e.g., Zablocka & Zernicki, 1996; Zablocka, Zernicki, & Kosmal, 1976; 1980)--they use alternative networks that are incapable of supporting normal expertise in some aspects of face processing.

REFERENCES

Aguirre, G.K, Singh, R., & D'Esposito, M. (1999) Stimulus inversion and the responses of face and object-sensitive cortical areas. *Neuroreport,* **10**, 189-194.

Bahrick, H. P., Bahrick, H. P., & Wittlinger, R. P. (1975). Fifty years of memory for names and faces: A cross-sectional approach. *Journal of Experimental Psychology: General,* **104**, 54-75.

Barton, J.J.S., Press, D.Z., Keenan, J.P., & O'Connor, M. (2002). Lesions of the fusiform face area impair perception of facial configuration in prosopagnosia. *Neurology*, **58**, 71-78.

Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996) Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience,* **8**, 551-565.

Bruce, V., Campbell, R. N., Doherty-Sneddon, G., Import, A., Langton, S., McAuley, S., & Wright, R. (2000). Testing face processing skills in children. *British Journal of Developmental Psychology,* **18**, 319-333.

Bruce, V., & Young, A.W. (1986). Understanding face recognition. *British Journal of Psychology,* **77**, 305-327.

Bruce, V., & Young, A. W. (1998). *In the eye of the beholder: The science of face perception.* (Oxford: Oxford University Press).

Campbell, R., & Tuck, M. (1995). Recognition of parts of famous-face photographs by children: an experimental note. *Perception,* **24**, 451-456.

Campbell, R., Walker, J., & Baron-Cohen, S. (1995). The development of differential use of inner and outer face features in familiar face identification. *Journal of Experimental Child Psychology,* **59**, 196-210.

Carey, S., & Diamond, R. (1977). From piecemeal to configurational representation of faces. *Science,* **195**, 312-313.

Carey, S., & Diamond, R., (1994). Are faces perceived as configurations more by adults than by children?. *Visual Cognition*, **1**, 253-274.

Carey, S., Diamond, R., & Woods, B. (1980). Development of face recognition: A maturational component?. *Developmental Psychology,* **16**, 257-269.

Cashon, C., & Cohen, L. (2001). Do 7-month-old infants process independent features or facial configurations? *Infant and Child Development,* **10**, 83-92.

Collishaw, S.M., & Hole, G.J. (2000). Featural and configural processes in the recognition of faces of different familiarity. *Perception*, **29**, 893-909.

de Haan, M., Pascalis, O., & Johnson, M.H. (2002). Specialization of neural mechanisms underlying face recognition in human infants. *Journal of Cognitive Neuroscience,* **14**, 199-209.

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

De Renzi, E. Perani, D., Carlesimo, G.A., Silveri, M.C., & Fazio, F. (1994). Prosopagnosia can be associated with damage confined to the right hemisphere – an MRI and PET study and review of the literature. *Neuropsychologia*, **32**, 893-902.

Deruelle, C., & de Schonen, S. (1995). Pattern processing in infancy: shape and location of components are not processed by the same hemisphere. *Infant Behavior and Development*, **18**, 123-132.

Deruelle, C. & de Schonen, S. (1998). Do the right and left hemispheres attend to the same visuo-spatial information within a face in infancy? *Developmental Neuropsychology*, **14**, 535-554.

de Schonen, S. & Mathivet, E. (1989). First come, first served: A scenario about the development of hemispheric specialization in face recognition during infancy. *European Bulletin of Cognitive Psychology,* **9**, 3-44.

Diamond, R. & Carey, S. (1986). Why faces are and are not special: An effect of expertise. *Journal of Experimental Psychology: General,* **115**, 107-117.

Ellemberg, D., Lewis, T.L., Maurer, D., Liu, C.H. & Brent, H.P. (1999). Spatial and temporal vision in patients treated for bilateral congenital cataracts. *Vision Research*, **39**, 3480-3489.

Eimer, M. (2000). Event-related brain potentials distinguish processing stages involved in face perception and recognition. *Clinical Neurophysiology*, **111**, 694-705.

Freire, A., & Lee, K. (2001). Face recognition in 4- to 7-year-olds: Processing of configural, featural, and paraphernalia information. *Journal of Experimental Child Psychology*, **80**, 347-371.

Freire, A., Lee, K., & Symons, L.A. (2000). The face-inversion effect as a deficit in the encoding of configural information: Direct evidence. *Perception*, **29**, 159-170.

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

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

Haxby, J.V., Gobbini, M.I., Furey, M.L., Ishai, A., Schouten, J.L., & Pietrini, P. (2001). Distributed and overlapping representations of faces and objects in ventral temporal cortex. *Science*, **293**, 2425-2430.

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

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

Kanwisher, N., McDermott, J., & Chun, M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *Journal of Neuroscience*, **17**, 4302-4311.

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

Kleiner, K. (1987). Amplitude and phase spectra as indices of infants' pattern preferences. *Infant Behaviour and Development*, **10**, 49-59.

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

Latour, S., Rousset S., Deruelle, C. & de Schonen S. (1999). Detection of degraded faces: an ability emerging from experience. *Poster presented at the National Meeting of Cognitive Sciences, Paris.*

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

Le Grand, R., Mondloch, C.J., Maurer, D., & Brent, H. (2002). Holistic face processing: The role of early visual experience. *Presented to Cognitive Neuroscience Society, SanFrancisco.*

Le Grand, R., Mondloch, C.J., Maurer, D., de Schonen, S., & Brent, H. (2002). Is that a face? The role of visual experience during infancy in the development of face detection. *Presented at the International Conference on Infant Studies, Toronto, Canada.*

Leder, H., & Bruce, V. (2000). When inverted faces are recognized: The role of configural information in face recognition. *The Quarterly Journal of Experimental Psychology*, **53**, 513-536.

Lewis, T.L., & Maurer, D. (1990). The development of temporal and nasal fields during infancy. *Vision Research*, **32**, 903-911.

Liegeois, F., Bentejac, L., & de Schonen, S. (2000). When does inter-hemispheric integration of visual events emerge in infancy? A developmental study on 19- to 28-month old infants. *Neuropsychologia*, **38**, 1382-1389.

Liu, J., Harris, A., & Kanwisher, N. (2002). Stages of processing in face perception: an MEG study. *Nature neuroscience*, **5**, 910-916.

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

Maurer, D. & Lewis, T.L. (2001). Visual acuity: the role of visual input in inducing postnatal change. *Clinical Neuroscience Research*, **1**, 239-247.

McCarthy, G., Puce, A., Belger, A., & Allison, T. (1999). Electrophysiological studies of human face perception. II: Response properties of face-specific potentials generated in occipitotemporal cortex. *Cerebral Cortex*, **9**, 431-444.

McCarthy, G., Puce, A., Gore, J., & Allison, T. (1997). Face-specific processing in the human fusiform gyrus. *Journal of Cognitive Neuroscience*, **9**, 605-610.

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

Mondloch, C.J., Le Grand, R., & Maurer, D. (2002b). Why is adult expertise in recognizing facial identity slow to develop? Recognizing chins, internal features, and the spacing among them. *Presented to the International Society for the Study of Behavioural Development, Ottawa, Canada.*

Mondloch, C.J., Le Grand, R., Maurer, D., & Brent, H. (2001). Early monocular deprivation affects the development of configural face processing. *Presented to Cognitive Neuroscience Society, New York.*

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**, 419-422.

Morton, J., & Johnson, M.H. (1991). Conspec and Conlearn: A two-process theory of infant face recognition. *Psychological Review*, **98**, 164-181.

Moscovitch, M., Winocur, G., & Behrman, 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**, 555-604.

O'Toole, A.J., Peterson, J., & Deffenbacher, K.A. (1996). An 'other-race effect' for categorizing faces by sex. *Perception*, **25**, 669-676.

Rhodes, G., Brake, S., & Atkinson, A., P (1993) What's lost in inverted faces? *Cognition*, **47**, 25-57.

Rodgriguez, E., George, N., Lachaux, J-P., Martinerie, J., Renault, B., & Varela, F.J. (1999). Perception's shadow: long-distance synchronization of human brain activity. *Nature*, **397**, 430-433.

Rossion, B., Gauthier, I., Tarr, M.J., Despland, P., Bruyer, R., Linotte, S., & Crommelinck, M. (2000). The N170 occipito-temporal component is delayed and enhanced to inverted faces but not to inverted objects: An electrophysiological account of face-specific processes in the human brain. *Neuroreport*, **11**, 69-74.

Rossion, B., Gauthier, I., Goffaux, V., Tarr, M.J., & Crommelinck, M. (2002). Expertise training with novel objects leads to left lateralized face-like electrophysiological responses. *Psychological Science*, **13**, 250-257.

Simion, F., Macchi Cassia, V., Turati, C., & Valenza, E. (2001). The origins of face perception: Specific versus non-specific mechanisms. *Infant and Child Development*, **10**, 59-65.

Tanaka, J.W., & Curran, T. (2001). A neural basis for expert object recognition. *Psychological Science*, **12**, 43-47.

Taylor, M.J., Edmonds, G.E., McCarthy, G., & Allison, T. (2001). Eyes first! eye processing develops before face processing in children. *Neuroreport*, **12**, 1671-1676.

Taylor, M.J., McCarthy, G., Saliba, E., & Degiovanni, E. (1999). ERP evidence of developmental changes in processing of faces. *Clinical Neurophysiology*, **100**, 910-915.

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

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

Zablocka T, & Zernicki B. (1996).Discrimination learning of grating orientation in visually deprived cats and the role of the superior colliculi. *Behavioral Neuroscience*, **110**, 621-625.

Zablocka T, Zernicki B, & Kosmal A. (1976). Visual cortex role in object discrimination in cats deprived of pattern vision from birth. *Acta Neurobiol Experimental*, **36**, 157-168.

Zablocka T, Zernicki B, & Kosmal A. (1980). Loss of object discrimination after ablation of the superior colliculs pretectum in binocularly deprived cats. *Behavioral Brain Research*, **1**, 521-531.