8. Monmonier, M. *Cartographies of Danger: Mapping Hazards in America* (Univ. Chicago Press, 1997).
9. Anisimov, O. A. & Nelson, F. E. *Climatic Change* **35,** 241–258 (1997).
10. Riseborough, D. W. in *Proc.Fifth Canadian Permafrost Conf.* (eds Burgess, M. M., Harry, D. G. & Sego, D. C.) 199–205 (Centre d'études nordiques, Université Laval/National Research Council of Canada, Québec, 1990).
11 Parmuzin, S. Y. & Shamanova, I. I. *Polar Geogr. Geol.* **10,** 184–193 (1986).
12. US National Imagery and Mapping Agency. *Digital Chart of the World for ADOL* (ESRI, Inc., Redlands, CA, 1997). URL: http://www.esri.com/data/online/esri/wobmselect.html
13. Scripter, M. W. *Ann. Assoc. Am. Geogr.* **60,** 385–393 (1970).

Neuroperception

Early visual experience and face processing

Adult-like expertise in processing face information takes years to develop[1] and is mediated in part by specialized cortical mechanisms[2] sensitive to the spacing of facial features (configural processing)[3]. Here we show that deprivation of patterned visual input from birth until 2–6 months of age results in permanent deficits in configural face processing. Even after more than nine years' recovery, patients treated for bilateral congenital cataracts were severely impaired at differentiating faces that differed only in the spacing of their features, but were normal in distinguishing those varying only in the shape of individual features. These findings indicate that early visual input is necessary for normal development of the neural architecture that will later specialize for configural processing of faces.

For face recognition, subtle differences in the shape of specific features (featural information) and/or in their spacing (configural information) must be encoded. We created two sets of faces that stimulated either configural or featural processing[4] (Fig. 1a, b). We asked 26 normal right-handed adults to view the faces from each set binocularly to decide whether they were the same or different when upright and inverted. Adults were equally accurate in differentiating faces from the two sets in their canonical upright position (Table 1). Inverting the faces decreased adults' accuracy for the configural but not the featural set, consistent with previous findings[4,5].

We used these stimuli to test face processing in 14 patients (6 male; 13 right-handed; 11 caucasian) born with a dense central cataract in each eye that prevented patterned stimulation from reaching the retina[6]. After removal of the natural lens, an optical correction was fitted to focus visual input (mean duration of deprivation, 118 days from birth; range, 62–187 days); patients had had at least nine years of visual experience after treatment before testing and, when necessary, wore an additional optical correction to focus the eyes at the testing distance.

Compared with age-matched normal subjects, the deprived patients distinguished faces from the featural set normally, but were significantly impaired for the configural set of upright faces (Table 1). Performance was not related to the duration of the deprivation for either set ($P > 0.10$; Fig. 1c). There was no correlation between acuity (range from 20/25 to 20/80 in the better eye; median, 20/40) and patients' accuracy on either set ($P > 0.10$).

Our results indicate that visual experience during the first few months of life is necessary for the normal development of expert face processing. Because normal infants have poor visual acuity[7], their cortex is exposed only to information of low spatial frequency which, for faces, specifies the global contour and location of features but little of their detail[8]**.** This early information sets up the neural architecture that will specialize in expert configural processing of faces over the next 10–12 years[9,10]. When visual input is delayed by as little as two months, permanent deficits result.

Patients performed normally in a different task requiring the discrimination of geometric patterns based on the location of an internal feature[11]. This suggests that deficits in configural processing may be restricted to the processing of faces, as expected from evidence that normal adults use separate systems for processing face and non-face objects[12,13].

Richard Le Grand*, Catherine J. Mondloch*, Daphne Maurer*†, Henry P. Brent†
**Department of Psychology, McMaster University, Hamilton L8S 4K1, Canada*
e-mail: maurer@mcmaster.ca
†The Hospital for Sick Children, 555 University Avenue, Toronto M5G 1X8, Canada

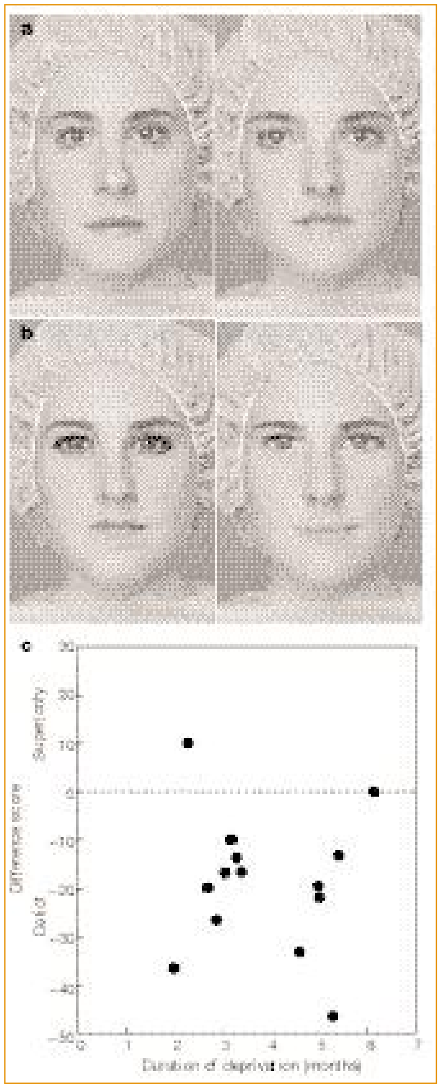

Figure 1 Measurement of configural versus featural processing. Examples of stimuli from **a,** the configural set (created by moving the eyes and mouth), and **b,** the featural set (created by replacing the eyes and mouth). On each trial, one of the five possible faces appeared for 200 ms, and following an interstimulus interval of 300 ms, a second face appeared until the subject used a joystick to signal a 'same' or 'different' judgement. **c,** Patients' performance on the upright configural set plotted as a function of the duration of deprivation from birth. Each circle represents the difference between the accuracy (per cent correct) of one patient and his/her aged-matched control.

Table 1 Detection of facial configural and featural differences

Group	N	Mean age (range)	Configural		Featural	
			Upright	Inverted	Upright	Inverted
Adults	26	19 (18–22)	80 (1.9)	63 (2.2)	80 (1.4)	81 (1.8)
Controls	14	14 (9–21)	81 (2.7)	59 (1.8)	79 (1.9)	80 (2.9)
Patients	14	14 (9–21)	62 (3.2)	55 (3.0)	80 (2.4)	78 (3.1)

Mean accuracy (per cent correct) and standard error are shown for detecting configural and featural differences in upright and inverted faces. There were 30 trials for each of the four conditions, which were presented in separate blocks. For adults, inversion decreased accuracy only for the configural set (significant interaction between orientation and stimulus set ($F_{1,25} = 49.78$, $P < 0.01$), followed by analysis of simple effects ($F_{1,27} = 62.57$, $P < 0.01$)). Patients were less accurate than controls (matched on age, gender, race and handedness) only for the upright configural set (significant interaction between group, orientation and stimulus set ($F_{1,26} = 8.99$, $P < 0.01$), followed by analysis of simple effects ($F_{1,26} = 16.26$, $P < 0.01$)).

1. Carey, S. & Diamond, R. *Vis. Cognit.* **1**, 253–274 (1994).
2. McCarthy, G., Puce, A., Gore, J. & Allison, J. *Cognit. Neurosci.* **9**, 605–610 (1997).
3. Bartlett, J. C. & Searcy, J. *Cognit. Psychol.* **25**, 281–316 (1993).
4. Freire, A., Lee, K. & Symons, L. A. *Perception* **29**, 159–170 (2000).
5. Tanaka, J. W. & Sengco, J. A. *Mem. Cognit.* **25**, 583–592 (1997).
6. Ellemberg, D., Lewis, T. L., Maurer, D., Liu, C. H. & Brent, H. P. *Vision Res.* **39**, 3480–3489 (1999).
7. Maurer, D. & Lewis, T. L. *Clin. Neurosci. Res.* (in the press).
8. de Schonen, S. & Mathivet, E. *Eur. Bull. Cogn. Psychol.* **9**, 3–44 (1989).
9. Diamond, R. & Carey, S. *J. Exp. Psychol. Gen.* **115**, 107–117 (1986).
10. Carey, S., Diamond, R. & Woods, B. *Dev. Psychol.* **16**, 257–269 (1980).
11. Geldart, S. thesis, McMaster Univ. (2000).
12. Kanwisher, N., McDermott, J. & Chun, M. M. *J. Neurosci.* **17**, 4302–4311 (1997).
13. Farah, M. J. *The Cognitive Neuroscience of Vision* (Blackwell, Maden, 2000).