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Review

Critical periods re-examined: Evidence from children treated for dense cataracts

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ABSTRACT

Studies of children treated for dense cataracts afford an opportunity to examine the role of visual experience in driving visual perceptual development. Collectively, the data indicate that there are multiple periods during which deprivation can damage visual development, but their timing and duration cannot be predicted from the normal developmental trajectory. For lower level vision, the deficits are worse in the previously deprived eye if the deprivation had been monocular rather than binocular, but for higher level perception, that pattern reverses, perhaps because of cross-modal neural completion during the deprivation. Emerging neuroimaging evidence suggests that the neural underpinnings of vision after early visual deprivation may be abnormal, even when the deprivation ended shortly after birth and normal behavioural performance has been achieved. The implication is that in the baby with normal eyes, despite poor acuity and contrast sensitivity, visual experience at birth sets up the neural architecture for later refinement.

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Infants can see as soon as they are born but there are serious limitations on their vision. Not only do they have limited acuity (Brown & Yamamoto, 1986) but they are not able to integrate the details of objects into a whole percept (Cohen & Younger, 1984) or discern the direction in which they move (Braddick, Birtles, Wattam-Bell, & Atkinson, 2005). There are rapid improvements over the first few months with the onset of sensitivity to direction of movement and configural cues at 2 months, and a fourfold improvement in acuity by 6 months (Braddick, Atkinson, & Wattam-Bell, 2003; Cohen & Younger, 1984; Mayer et al., 1995). Nevertheless, it takes into adolescence (Golarai, Liberman, Yoon, & Grill-Spector, 2010)—and perhaps even longer (Germine, Duchaine, & Nakayama, 2011)—for all aspects of visual perception to become adult-like.

We have studied the role of visual input in driving these postnatal changes. We have done so by taking advantage of a natural experiment: children born with dense central cataracts that blocked all patterned input to the retina until the

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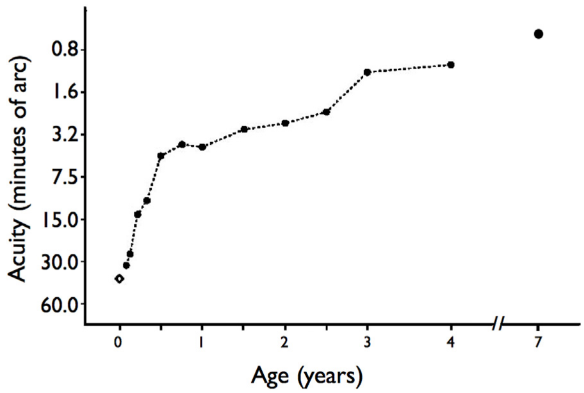

Fig. 1. The development of visual acuity in children with normal eyes. Shown are the size of the smallest stripes for which children show a looking preference at ages from birth (0 years) to 7 years, when acuity reaches adult levels. Acuity is shown in minutes of arc, the size on the retina of the threshold stripes, such that smaller values represent better acuity. Reprinted from Lewis and Maurer (2005).

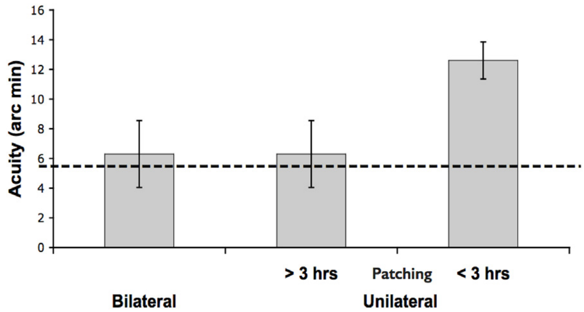

Fig. 2. Mean acuity ±1s.e. at 12 months of age for infants treated for congenital cataracts that were bilateral or unilateral. The results for unilateral patients are divided into those from patients whose fellow eye was patched for at least 3 waking hours from the time of treatment until the first birthday and those for whom there was less patching. The dotted line shows the normal value at 12 months of age. The abscissa shows acuity as the size in minute of arc of the smallest stripes for which there was a looking preference, with better acuity represented by smaller values. Bilateral patients had normalized by the first birthday, as had unilateral patients with extensive patching. Reprinted from Lewis and Maurer (2005).

cataracts were removed and the eyes fitted with compensatory contact lenses. In the patients we studied, this occurred as early as the first month of life to as late as 9 months postnatally. Comparisons of these patients to children with normal eyes allowed us to deduce the role of normal visual experience in driving normal postnatal changes in visual perception. Correlation of the outcome for parents with the duration of the initial deprivation allowed us to draw inferences about the role of patterned input at different points during infancy, as did parallel studies with children born with normal eyes who developed cataracts postnatally. We have studied many aspects of vision in these patients; here I will illustrate our findings with the results for acuity, sensitivity to global motion, and face perception.

1. Acuity

Newborns' acuity has been measured using their tendency to look at something patterned like stripes in preference to a plain grey. Newborns show a robust preference as long as the stripes are large and contrasty: 60 times larger than the limit for adults with normal vision (Brown & Yamamoto, 1986) and 100–200 times more contrasty (Brown, Lindsey, Cammenga, Giannone, & Stenger, 2015). Over the first 6 months there is rapid improvement, followed by slower increments until adult levels are reached around 7 years of age (Ellemberg, Lewis, Liu, & Maurer, 1999; Mayer et al., 1995) (see Fig. 1). Our studies of infants treated for bilateral congenital cataract indicated that visual experience is necessary for the initial rapid change: when it was missing, no improvement occurred. These infants had surgery to remove the cataracts and 1–2 weeks later, after the eye had healed, received contact lenses to focus visual input. Within 10 min of that time—the first moment of receiving focused patterned visual input, their acuity was like that of a normal newborn (Maurer, Lewis, Brent, & Levin, 1999). The rapid changes seen in babies with normal eyes had not occurred. But the system had not been dormant during the visual deprivation: after the first hour of visual input, there was a significant improvement in acuity, not seen in control infants. Patients continued to improve faster than control age mates, so that by the first birthday, almost all had acuity within normal limits (see Fig. 2). This pattern indicates that the system is experience-expectant: during the period of visual deprivation, the patients' nervous system was becoming increasingly ready to respond to visual input, once it was received. As a result,