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Natural History of the Development of Visual Acuity in Infants

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Summary
A selective review of the contemporary understanding of development of infant visual acuity is presented together with recent developments in methodology to detect this change. References are confined, wherever possible, to human infant studies relating to factors explaining the development of acuity. Results obtained from a two year study of the development of grating acuity in normal infants are discussed briefly. The findings indicate the importance of establishing acuity norms and sensitivity of interocular acuity difference as an important parameter in the detection of monocular visual deficit in clinical practice.

Normal visual development in infants is characterised by a striking imaturity at birth followed by rapid development of visual functions which reach adult levels by about five years age. Modern biochemical and histological techniques in anatomy and single unit receptor recordings in physiology have contributed a great deal to the understanding of development of visual functions in infancy and early childhood.

Over the past 20 years a wide variety of behavioural and electrophysiological methods have been adapted in research laboratories to detect and measure the development of visual functions such as grating and vernier acuity, contrast sensitivity, colour vision and visual field size. These have helped to overcome the interface between anatomical and physiological aspects of the developing visual system. Assessment of acuity has been the most commonly studied function.

Review of Literature

Three main changes underlie improvement in acuity: macular differentiation, myelination of the visual pathway and changes in dorsal lateral geniculate nucleus and striate cortex.

Until recently foveal development was thought to be complete by 4 to 6 months. However, a detailed study by Hendrickson and Yuodelilis[1] has revealed a much longer time course. At 15 months the cones are half the adult length and only by 45 months is the macular area adult like. Though the inner segments of the cone develops before birth, the outer segments develop after birth indicating postnatal maturation. Peripheral migration from the foveolar area of the bipolar, amacrine, horizontal and ganglion cells is complete by 15–45 months. A progressive increase in cone population density by central migration takes place over a time course of three years.

Magoon and Robb[2] demonstrated that myelination of the human optic tract proceeds centrifugally towards the optic nerve. Myelin was detected in few fibres of the optic tract at 32 weeks gestation and fibres in the intraorbital section of the optic nerve appeared only at term. The density of myelin increased rapidly for two years and gradually thereafter. Myelination of the subcortical pathways is

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complete by three months and that of the extrastriate areas is only complete by mid-childhood.[3]

In the dorsal lateral geniculate nucleus adult appearances are reached by 12 months in the parvocellular layers and by two years in the magnocellular layers.[4] The infant striate cortex initially shows an increase in the population of spines and synaptic density for the first eight months followed by a decrease in both counts with adult population levels reached by the age of eleven.[5]

Single unit recordings from dorsal lateral geniculate nucleus in monkey infants provide evidence of an increase in spatial resolution (from 5 to 35 cycles/degree) over the first 30 postnatal weeks in the neurones subserving the central two degrees of the visual field.[6,7] Similar limitations in resolution capabilities are not seen in neurones in the peripheral visual field. Analogous developmental changes are seen in cortical neurones with newborns showing lower contrast sensitivity functions and resolution capabilities than adults by a factor of six.[8] Therefore anatomical maturation and physiological changes appear to be the critical factors for the improvement in visual acuity over the first three years of life.

Modern methods such as Preferential Looking (PL) and Visually Evoked Cortical Potentials (VEP) are now well established in developmental literature as valid methods for measurement of acuity in infants.

Fantz *et al*[9] in 1962 utilised the behavioural response of the infant to gaze at patterned targets, in preference to blank areas. This formed the basis of PL. Visual acuity is estimated by observing an infant's fixation behaviour when presented with targets (vertical bar gratings) of increasing spatial frequency on either the left or right side in a plain background until the child appears to show no preference for the target.

Teller and other workers [10–12] used a forced-choice method with the observer masked to the location and spatial frequency of the grating. It's variation; Operant PL[13,14] introduced rewards for correct responses to act as reinforcement and increase cooperation in older children. The Acuity Card Procedure[15] with Teller Acuity Cards has been recommended as a practical alternative to sophisticated equipment required for forced choice methods. For detailed reviews see Dobson and Teller 1978, Simons 1983, Teller *et al.*, 1986, Pearson *et al.*, 1989.[11,16–18]

Comparison of improvement in grating acuity in full term and preterm infants has shown that preterm infants lag behind full term infants up to eight months of age.[19,20,21] When the age of preterm infants was corrected to term or post conceptional age, acuity for the two groups was similar.[19,21] Similar trends are also seen for monocular optokinetic nystagmus and visual field size.

Assessment of development of binocular grating acuity measured in normal full term infants with forced-choice and operant methods from different laboratories show consistent results. Grating acuity shows a steady improvement from about 0.5–1 cycle/degree at birth to reach adult levels by about five years of age. Similar improvement in monocular acuity with the acuity card procedure has been reported from various laboratories.[17,22] Mean monocular acuity improves from 0.6 to 25 cycles/degree for an age span of four weeks to 36 months of age. Across studies binocular acuity estimates were higher than monocular estimates by 0.5–1 octave. An octave represents a doubling or halving of spatial frequency.

In a single centre study, Birch and Hale[22] in 1988 reported higher PL acuity estimates for the neonate than most previous studies.[21,23] Mean acuities of 1.81 cycles/degree at 0–2 months in comparison to 0.7–1.0 cycles/degree. However, similar to other studies adult acuity levels (32 cycles/degree) were only attained by five years of age.

There are some remaining problems. The shape of psychometric functions in forced-choice methods; presentation strategies for staircase methods and the possibility of observer bias in the acuity card procedure remain to be resolved before widespread use can be recommended. PL has been used effectively to detect grating acuity development but a standardised multicentre assessment to establish acuity norms is still needed.

Electrophysiological studies of infant acuity development have mainly employed VEP techniques. The current methodology and role of VEP in infant visual development is briefly discussed here.

In pattern VEP studies in infants, VEP amplitude as a function of spatial frequency, extrapolated to zero microvolt has been used as a measure of infant acuity.[24] A number of studies in adults have shown that this corresponds well with psychophysical threshold.[25,26] It remains to be established whether the same holds true in the case of a rapidly developing visual pathway.

Sokol[25] using pattern reversal VEPs found a roughly linear increase in log acuity with adult acuity levels being reached by seven months of age.

Norcia and Tyler[27] and recently Hamer *et al.*[28] from the same laboratory have measured VEP acuity for the first year of life with a sweep VEP technique. Binocular mean sweep acuity in cycles/degree increased from 4.5 cycles/degree in the first month to 20 cycles/degree by twelve months of age. Hamer *et al.*[28] reported similar rapid increase in acuity for monocular tests. There did not appear to be a superiority of binocular over monocular acuities. Though both studies found some children with adult acuity levels at eight months, mean acuities for the 8–13-month age group were still below adult mean acuity levels.

Acuities estimated by VEP methods also show rapid development for the first six months. Adult acuity levels are apparently reached by seven to eight months of the infant's life. Acuity estimates obtained by the sweep VEP method are higher, especially in the neonate, than other evoked potential studies.[24,29] The most likely explanation put forward is the difference in the time taken for obtaining an acuity estimate. Sweep VEP methods required only a 10-second trial. This is supposed to help in gaining maximum information from infants who may rapidly lose interest. Differences in stimuli, analysis techniques and luminance conditions may also account for the variation between VEP methods.

VEP estimates are higher than PL acuity estimates and may differ by as much as two to three octaves: an important difference when compared to PL results where adult acuity levels are reached only by approximately five years. Two entirely different techniques cannot be wholly comparable. However, a few reasons for the variance in acuity measures may be postulated. First, scoring criteria for PL estimates are based on 70% correct responses which are more conservative than VEP scoring criteria.[11] Second, the size and placement of stimuli. VEP stimuli are thought to measure foveal function. PL stimuli are larger and their peripheral placement may stimulate extrafoveal regions before the psychophysical response leads to foveal fixation. Finally, the two methods may provide information regarding different aspects of visual function and may be complementary.

Evaluation of PL in Clinical Practice

At Bristol we have evaluated preferential looking methods in clinical practice. As part of the process, 150 normal children were examined to determine the natural course of development of grating acuity in infancy and early childhood. We used Teller Acuity Cards which were displayed through circular apertures in the central display area of a grey screen (Fig. 1). The cards consist of a set of 16, each with a high contrast black and white grating printed in a square patch on one side of a grey background. The gratings range from 0.32 to 38 cycles/cm in half octave steps. Monocular acuity estimates were obtained with a two up one down staircase procedure.[30]

The acuity measures and the interocular acuity differences (IAD) obtained, were analysed by relatively new nonparametric statistical smoothing methods[31] to show acuity growth as a function of age. Comparative analysis was done to establish criteria for the detection of acuity deficits in infants (details of analysis to be published separately).

The median acuity curve for both eyes showed a rapid increase up to 38 weeks of age with a subsequent relatively slower increase in acuity continuing at least until three years of age (Fig. 2). This trend agrees well with the time course of development from anatomical studies and evidence from single unit recordings mentioned earlier.

Rapid development of monocular grating acuity obtained in our study for infants less than six months of age is in general agreement with other similar studies. There are discrepancies in the mean acuity values for different

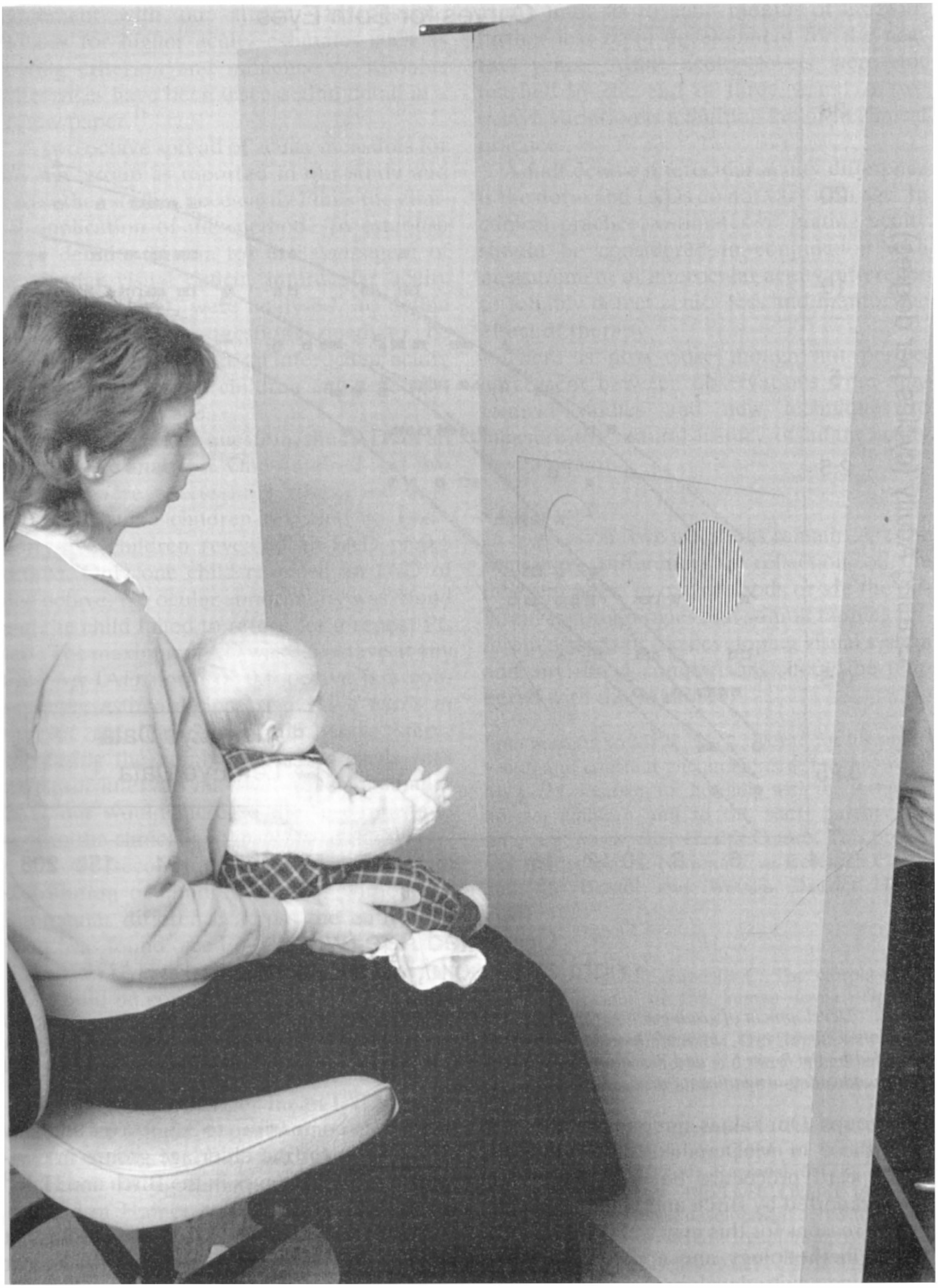

Fig. 1. *A screen (Bristol University Screen) was specially designed for the study. Teller Acuity Cards were displayed through circular apertures in the central display area. The infant was held in the parent's lap; older children sat independently on the chair. The child's response was observed through a central peephole in the cards by the observer seated behind the screen.*

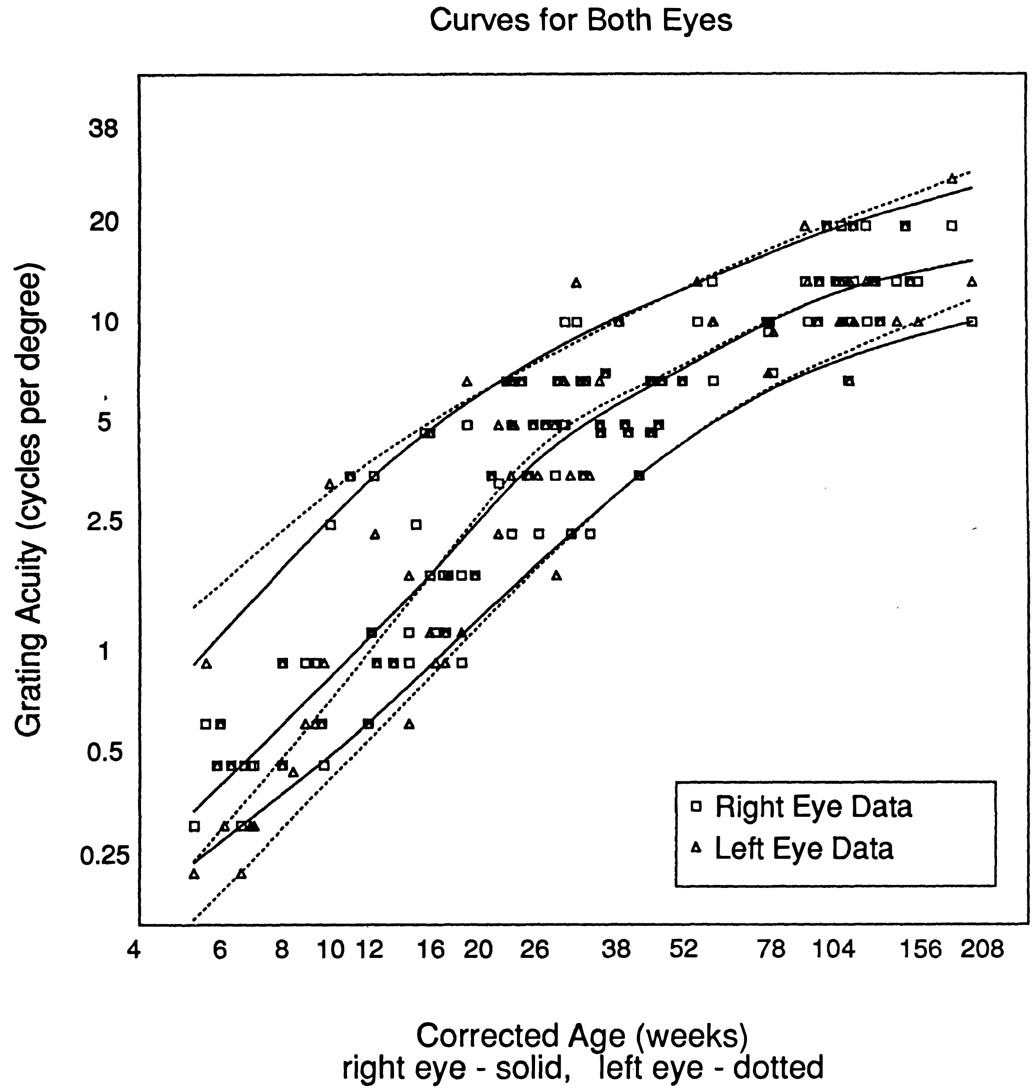

Fig. 2. *Development of grating acuity. These acuity growth curves are based on 114 right (solid curves) and 109 left (dotted curves) eyes, successfully tested from a population sample of 150 children. The central median curve is bounded by the lower 5% and the upper 95% curves. Right and left eye curves follow a similar developmental course indicating insignificant interocular acuity difference.*

age groups. Our values agree reasonably well with those of McDonald *et al.*[32] using the acuity card procedure but are lower than those reported by Birch and Hale.[22]

The reasons for this may well lie in the different methodology and apparatus used to determine acuity development. However, in comparison we have obtained a significantly narrower spread of acuities. In our study, for the first year of life the average range is 2.1 octaves in comparison to 3.3 octaves and only 1.1 octaves for the older age groups in comparison to 2.0 octaves in the Birch and Hale[22] study.

It may be worthwhile to compare our first year acuity data with that published by Hamer *et al.*[28] using a sweep VEP method. The average acuities are higher than most other VEP studies and certainly far higher than our study. The two octave spread of acuity measures is in agreement with our study. The possible reasons for higher acuity estimates such as scoring criterion and influence of stimulus differences have been discussed in detail in a review paper.[11]

A two octave spread of acuity measures for any age group as reported in our study and from other studies necessarily limits the clinical application of the method. To establish more definite criteria for the assessment of monocular visual deficit, interocular acuity differences (IAD) were analysed. To define IAD norms, two questions need to be answered. First, is there an interocular acuity difference in normal children and secondly, does it vary with age.

To answer the first question, the IADs of all infants were analysed. One-hundred-and-five children were successfully tested for both eyes. Fifty-nine children revealed no IAD. Forty-five children revealed an IAD of 0.5 octave. Only one child revealed an IAD of one octave. No ocular abnormality was found and the child failed to return for a repeat PL test. The maximum IAD was 0.5 octave at any age. An IAD norm of 0.5 octave is a conservative estimate since successive cards in the set are limited to half octave steps. Increasing the number of acuity cards with narrower intervals may well reveal a smaller IAD but would increase the test time and reduce the clinical applicability of the test.

For the second question, shows an equal distribution of children with or without an interocular difference across the entire age span, was found (see Fig 2).

Thus an IAD of more than 0.5 octave at any age would be considered abnormal. In comparison to the 2.0 octave variation in acuity curves; IAD is a more specific indicator of monocular acuity deficit.

Birch[33] reported larger mean IADs of 1.5 octaves for infants less than one year of age and 0.9 octaves for older children. Our results are more in agreement with sweep VEP method of Hamer *et al.*[28] where IADs were invariant and not significant at any age.

In summary, the study of development of grating visual acuity and establishing norms is essential for future implementation of modern methods in clinical practice. The results of our study reveal a rapid development of visual acuity until six to eight months of life with further less rapid development for the next two years. Adult acuity levels were not reached by the end of three years. A two octave variation is a limiting factor in clinical practice.

A half octave interocular acuity difference is the norm and IADs do not vary with age. In clinical practice, estimates of grating acuity should be considered in conjunction with measurement of interocular acuity difference to reliably detect acuity loss and minitor the effect of therapy.

There is now close though not perfect agreement between observations from anatomical studies and new techniques to measure the natural history of infant acuity development.

Conclusion

In conclusion, two questions remain. Are the remaining differences a reflection of the inherent noise in our methods or are the different methodologies and stimuli tapping different aspects of the developing visual system and any direct comparisons should be tempered with this in mind?

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