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Development of visual functions I

YOUNG CHILDREN'S VISION PART 1 COURSE CODE C-17961 O/D

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Many optometrists (with the exception of those working in the hospital eye service) will not often expect to examine children before their first birthday. Even so, an appreciation of how the eyes develop long before the first examination takes place is important in understanding the stages the visual system will have reached at that first optometric visit. This article looks at the very early development of ocular and visual function.

Measuring visual function in infants

For research purposes, laboratory techniques such as visual evoked potentials (VEPs), electroretinograms, and optokinetic nystagmus (OKN) can, and have, been used to study visual development. There are also techniques that rely on observation of an infant's responses to a visual stimulus. The one that has translated into clinical assessment is preferential looking (PL).

At birth, a child has useful sight and is eager to use it. Babies fixate on bright, bold targets, apparently driven by the need to obtain stimulation of the visual areas of the brain – this is the origin of

the 'preferential looking' technique. Babies will 'choose' to look at a target containing more, as opposed to less, information. There is some evidence that a face is a particularly attractive target even just after birth. One study demonstrated preference for a face-like stimulus, in a group of 40 infants with an average age of nine minutes!¹ Certainly a face remains one of the most salient objects for a baby to enjoy looking at (see Figure 1). In fact, sometimes it can be quite frustrating when trying to interest a baby in a vision test, to find that the baby is only interested in the examiner's face!

In the PL technique, a child is shown two targets (for example on screens to the right and left of straight ahead) and the observer notes the first eye movement towards a target, or the direction in which the child spends most time looking. For functions such as visual acuity (VA), one screen is blank, but brightness matched to a grating. If the acuity target is visible, the child will show a clear preference for looking towards it and the observer can accurately predict the position

of the grating. If the acuity target is beyond the child's threshold, there will be no apparent difference between the two and the observer will not be able to reliably estimate the grating's position. For discrimination tasks, there may be two targets visible; if the child shows a preference for one, then he/she can see a difference between them.

The technique of 'habituation' is a more reliable way of determining a child's discrimination. This relies on a child becoming 'bored' by a target that is repeatedly shown. Once a child's looking responses to the repeated stimulus decrease, a novel target is introduced. If the looking response picks up again, then the child can obviously see the difference and prefers a new experience. This technique can be used to study colour discrimination, orientation discrimination and so on.

A third technique is operant conditioning, in which a child is 'trained' to respond to a stimulus in order to gain a reward. Unlike animal studies, in which the reward will be food, for infants the reward is more usually some fun interaction with the examiner such as 'peek-a-boo'. Once the child responds reliably to a stimulus (the response may be pressing a switch) a novel target can be introduced. As with habituation, the question is, does the child recognise that this is a new stimulus? In this technique the expectation is that the child will not respond to the unfamiliar target.

While habituation and operant conditioning have taught us a great deal about the pace of visual development in children, the techniques are clearly laborious and do not lend themselves to clinical evaluation. Fortunately PL is adaptable to the clinical situation and is worth optometrists becoming familiar with to enable examination of a child of any age. The technique will be described in detail in article three of this series.



Figure 1
Oscar clearly enjoys looking at his mum Jo's face



Visual acuity

Acuity in infancy is measured by PL with black/white gratings. Later, of course, recognition acuity can be measured with picture or letter targets familiar to a child. It is important to note that the acuity score for any child will be highly dependent on the technique and target, so scores with different tests are generally not comparable. The acuity scores presented in Figure 2 are therefore general guidelines to illustrate the improvement in acuity with age. If a practitioner is measuring acuity in a child, it is vital that he/she refers to the expected norms for the particular test they are using.

It is impossible to predict at what age a child should reach 'adult' acuity, because much depends on non-visual factors such as familiarity, confidence and willingness to guess. Figure 2 shows a very rapid increase in VA in the first few months of life, followed by a much more gradual improvement. Possibly of more importance than the mean scores is the wide range of normal values in healthy infants (approximately 95% of all scores lie within two standard deviations of the mean). Just as babies differ considerably in the age at which they first sit up or walk, so they also vary in their visual development. However, any individual child would be expected to make progress in acuity with age. A child whose VA decreased or remained constant, even though scores may lie within the normal limits on each occasion, would give cause for concern.

Inter-ocular differences are generally very small in the normal case. In the study reported in Figure 2, 72% of children showed no difference in acuity between the two eyes and 99% showed either zero or only one acuity step difference between the eyes. This was the case even for the youngest subjects. Thus both retinal and cortical maturation that give rise to the improving acuity seems to be remarkably

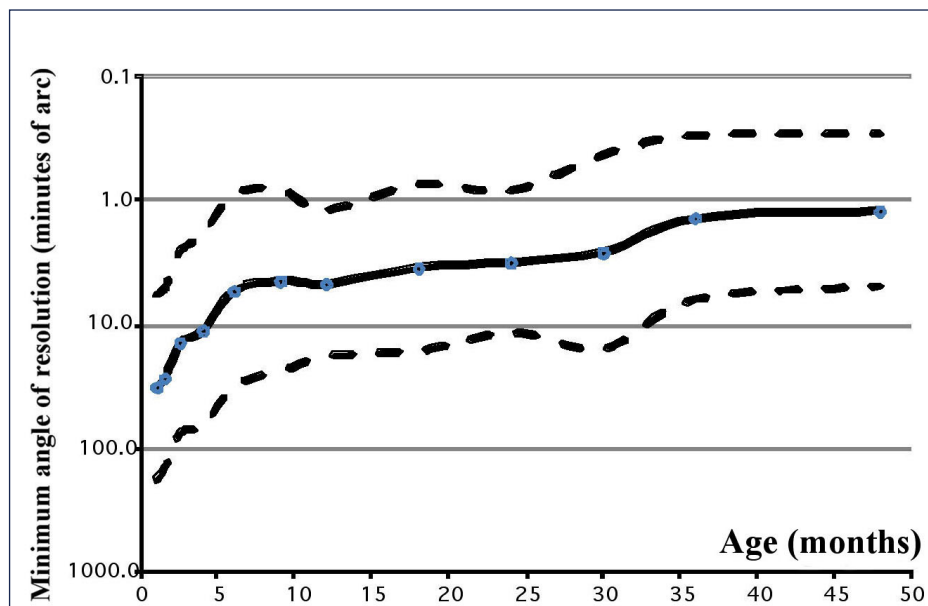


Figure 2

Development of visual acuity as measured by PL, data from Mayer et al.³ Grating acuity is correctly expressed as cycles per degree, but here are converted to minimum angle of resolution. Markers show mean values; dashed lines represent ± 2 standard deviations.

well co-ordinated between the two eyes.

Contrast sensitivity

Contrast sensitivity (CS) is relatively poor at birth, but develops quite rapidly. Sensitivity to low spatial frequencies (large targets) develops much earlier than sensitivity to high spatial frequencies.² However, an optometrist is unlikely to want to plot an entire contrast sensitivity function for a child of any age, so expected values for clinical tests using one stimulus size are more relevant. For two readily available tests, the Hiding Heidi and Lea symbols, there does not appear to be any change in score with age for children aged one year and above.⁴ For the Cardiff Contrast Test,⁵ one-year-olds show a poorer contrast sensitivity than older children, but for 2-5 year olds there is little, if any, improvement with age. These findings suggest that, while VA appears to continue improving throughout early childhood, contrast sensitivity for larger targets is complete and adult-like within the first

two years. Actual values for both VA and CS will, of course, depend on the method of testing and on the criterion chosen for threshold, so practitioners should familiarise themselves not only with the published norms as numeric values, but with the particular techniques used to determine norms.

Binocular vision

A great deal of research has been devoted to studying the onset of binocular vision in infancy. Results depend, of course, on what is measured ie, the definition of binocular vision. However, there is general agreement that in the first two months of life, vision appears to be monocular, and there is no difference in an infant's response, or in objective measures such as cortical potentials, when a similar stimulus is presented to both eyes as opposed to one.⁶ By three months, some infants show a preference (by behavioural observation such as PL) and demonstrate recognisable binocular

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cortical potentials. The most convincing studies are, arguably, those that use so-called 'cyclopean stimuli', in which a target is visible only when inputs from the two eyes are combined (such as random dot stereograms). While there is considerable individual variation in the age at which infants respond to these stimuli, most studies agree that the majority of children show binocular vision by four months.

The ability to combine the input from both eyes is dependent, not only on binocular cortical processing, but also on accurate alignment of the eyes' axes (ie, convergence). Studies appear to show a similar time-line for development; most infants' vergence system is developed by four months of age.

In the early weeks, eye alignment can be inaccurate with brief instances of strabismus in tiny infants. Until recently, most of the literature reported that misalignments were exo in direction. The orthoptist Anna Horwood noted the discrepancy between the literature and parent reports that babies' eyes turned inwards (eso direction). Horwood was ideally placed to settle the issue;⁷ she recruited 75 pregnant orthoptists who subsequently kept precise records of their infants' eye alignment in the early months. Most infants showed misalignments in the first two months, with almost all instances an eso-deviation. Horwood concluded that, when examined by a clinician, infants have little interest in the person holding them, and are therefore not motivated to converge accurately; hence the observation by professionals that infants' eyes drift outwards. When interacting with a mother (and no doubt with any other close family member) infants are more likely to converge accurately or even to over-converge. In the study, most misalignments had disappeared by four months of age, and the only ones persisting were likely to lead to a diagnosis of infantile esotropia.



Figure 3

By the age of 14 months, Eve has eyes that are fully aligned, she is interested in objects at a distance and, when she turns to look at her hands, enjoys exploring small objects at near

This study is a fascinating example of sound clinical research and a prime example of mothers knowing best!

Most childhood strabismus is esotropia, which can be classed as fully accommodative (if the deviation is corrected with plus lenses), partially accommodative (if the deviation is lessened but not corrected with plus lenses) or non-accommodative (no hypermetropia or the deviation is not effected by spectacles). Studies suggest that the mean age of onset is three years.^{8,9}

Colour vision

Testing colour vision in infants is challenging, because of the difficulty in determining that a PL response is triggered by a chromatic difference between the stimuli rather than a luminance difference. The luminous sensitivity of an infant visual system to different wavelengths cannot be assumed. The precise way in which the experiments are carried out is beyond the scope of this article, and the interested reader is directed to the literature.¹⁰ Most studies show that no colour response manifests in infants before two months of

age. The first clear response is recorded to red-green discriminations; it appears that the blue or tritan system develops about a month later. It is also reported that infants show a preference for red – confirmation of what parents and toy manufacturers had already figured out!

Eye movements

Young infants can make saccades to fixate an object of interest. However, the saccades tend to be small, so an object of interest is reached by a series of small eye movements rather than by one large one. Head movements are also prominent.

Smooth pursuit (tracking) is very difficult to elicit before one month of age. After that, a baby can track smoothly only at very slow speeds (around 10 degrees per second). If the motility target moves more quickly, the infant resorts to following by saccades and head movements.¹¹

Children's responses to eye movement assessment such as motility testing are very variable and highly dependent on the target used.¹² A practitioner needs to consider how motivated a child will be to track an uninteresting stimulus. Most eye movement functions (such as latency or gain) show an improvement with age, but it is impossible to predict at what age a child's eye movement responses can be considered adult-like.

Ocular reflexes

Infants blink far less frequently than adults. Young infants show a startle blink response to loud noises or sudden onset lights, but they may not blink to an approaching visual stimulus as would an adult. A corneal response (to touch) is also absent in most babies in the early days and is only demonstrable in all babies by three months of age.¹³ Parents can sometimes be concerned by their baby's lack of response and need reassurance.



The pupillary light and near responses are present from birth, but responses may be smaller and more sluggish than in adults.

OKN can be demonstrated from birth, provided the stimulus moves slowly enough and is shown binocularly. However, monocular OKN can only be elicited in the temporalward to nasalward direction⁶ before about three months of age. The development of symmetrical OKN (ie, the onset of nasalward-temporalward monocular responses) has been linked to the onset of binocularity, since OKN remains asymmetrical in strabismus.

Visual behavioural changes

As well as having an understanding of research findings with regard to visual functions, practitioners should familiarise themselves with the day-to-day changes in a child's visual responses that parents and family members will notice. These are summarised as follows:

- In the first six weeks of life, a baby will stare at large, bright objects, blink in response to sudden sounds or bright

lights and follow slow moving objects with small jerky eye movements, with two eyes that are mainly aligned but with occasional inward turns.

- From two to six months, a baby's eye movements will become smoother, although tracking will also involve the head. A baby will begin to look at his/her hands and particularly at faces. Parents should notice fewer episodes of an eye drifting in.
- From six to 12 months, a baby is able to track a moving object with less head movement, and to look for objects of interest. Baby begins to pay more attention to people and objects at a distance rather than just within arms' reach. Eyes should be fully co-ordinated.
- From 12 to 18 months a baby begins to recognise objects, toys and pictures and to point them out. A baby uses both hands to bring objects close and will enjoy exploring toys (Figure 3).

Conclusion

From the rudimentary capabilities of a

child at birth, vision and visual functions develop rapidly over the first few months of life. By the time a child is 4-6 months old, contrast sensitivity, colour vision, eye alignment, and binocular vision are all quite advanced and eye movement control is good for tracking slow objects. VA appears to be the last function to fully mature, and continues to refine for the first few years.

About the author

Maggie Woodhouse is senior lecturer at the School of Optometry & Vision Sciences, Cardiff University, where she specialises in paediatric optometry. She runs the Special Assessment Clinic, which caters for patients of all ages with disabilities. Her particular interests are visual development in children with Down's syndrome and the impact of visual defects on education.

References

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1. All of the following are considered to be reliable ways of measuring visual function in a child aged two months EXCEPT:

- Preferential looking
- The blink reflex to a looming object
- Tracking a slow moving object
- Habituation

2. In a child aged two months, all of the following factors might influence the VA score obtained EXCEPT:

- The technique used for measurement
- The criterion for determining threshold
- Binocular vs. monocular testing
- Whether the examiner's face is visible to the child

3. According to Figure 2, at what age would a VA of 6/60 equivalent be considered abnormal in a child?

- Three years
- Two years
- 20 months
- 10 months

4. The development of contrast sensitivity:

- Matures earlier for high spatial frequencies than low spatial frequencies
- Is not measurable until three months of age
- Runs parallel with VA for all target sizes
- Matures within the first 12 months of life for large targets

5. Considering binocular vision in young children:

- Intermittent exotropia is common in the first few weeks
- Most infants can accurately converge and diverge by four months of age
- Occasional eso-deviations at two months require referral to the HES
- Stereopsis is not measurable before six months of age

6. Considering early visual development:

- Infants prefer a familiar stimulus rather than a new stimulus
- Infants prefer a plainer stimulus rather than a highly detailed stimulus
- Saccades develop before pursuit eye movements
- For the right eye, left-right monocular OKN develops sooner than right-left