Introduction

The normal visual development occurs from birth up to the age of 10-12 years, and requires a normal visual system. Research during the last decades has emphasized the importance of adequate visual stimulation during the first months and years of life. It is therefore of great importance to identify children with subnormal vision early in life to start treatment and habilitation. A prerequisite is that reliable testing methods are available and can reveal visual defects as early as possible. The visual acuity testing methods in children can be divided into 3 subgroups according to the types of stimulus used; detection, resolution and recognition acuity. Different acuity values are usually obtained with the different tests. Contrast sensitivity measurements can reveal changes and loss of visual function that is not detected when testing visual acuity. Sweep-VEP could become a valuable test to assess vision in young children in a clinical setting.

Normal visual development

What can a newborn child see and how does the vision develop? A newborn child can hear quite well, but the vision is subnormal and has not developed much. A newborn baby can fixate a light, and from birth up to 4 weeks the baby starts to fixate and follow objects presented closer than 1 meter. At about 2-3 months the child can fixate and follow an object at 2-3 meters. Eye contact is usually said to be developed at 4-7 weeks, and at 8-12 weeks the child starts to play with its own fingers in front of the eyes.
The visual acuity, recorded as Snellen decimal acuity, is approximately 0.01-0.05 in a newborn child, 0.1 at 6-12 months, 0.25 at 2 years, 0.5-0.65 at 3 years, 0.8 at 4 years and 1.0 at 6 years. Not until the age of 10 -12 years the visual acuity is fully developed, approximately 1.3-1.6. However, the acuity values depend to a great extent on the methods used in the examination and this issue will be discussed in more detail later in this chapter.

Development of the visual pathways

The subnormal vision in young children is due to the immaturity of the eye and the whole visual system—the retina, optic nerve, chiasma, lateral geniculate body, optical radiation, and visual cortex. At birth the axial length of the human eye is about 17 mm (or 3/4 of adult size), and by 13 years of age the eye has reached adult size, and an axial length of 23 mm. The fovea is immature at birth. In the fetal eye cup it appears as an elevation formed by the ganglion cells. The ganglion cells migrate peripherally during the first 25 weeks of fetal life to form the foveal pit. The retina and especially the fovea will reach full maturity at about 4 years of age. The main change is in the density and spread of cones in the retina during this period. The myelination of the optic nerves begins in the lateral geniculate nucleus, reaches the orbital part of the optic nerve at full term, and continues towards the retina over the following 2 years. The maturity of the lateral geniculate body and the visual cortex also take place during the first 4 years of life. Studies of vision in monkeys, with a visual system very similar to that of the human, have shown that the visual acuity during the first years is much lower than what could be expected from the structure of the retinal and the neuronal elements. However, at higher ages it correlates quite well to morphological parameters. The development of the still higher visual acuity in adulthood is mainly due to the maturity of the higher visual systems in the brain beyond the visual cortex.

The sensitive period

The plastic period (also called the sensitive period or the critical period) of the visual development is the time during which the visual acuity is developing and can be modified. The Nobel laureates of 1981, Professor Torsten Wiesel (honorary president of the Sigvard and Marianne Bernadotte Research Foundation for Children Eye Care) and professor David Hubel, already in 1963 established the norms for the sensitive period in cats and monkeys. The period for cats is up to 16 weeks and in monkeys up to 30 weeks. In the human the
sensitive period proceeds up to 8-10 years of age with the most critical part during the first 2-3 months.

**Abnormal visual development**

The normal visual development requires a normal visual system. Different eye diseases such as congenital cataract, strabismus, refractive errors (especially astigmatism and high hyperopia), ptosis, lid hemangioma etc. will prevent clear vision and retard visual development. Amblyopia (amblyos= lazy, opia= vision) is a common visual sequelae to such eye disorders. It is defined as a unilateral or bilateral decrease of visual acuity caused by pattern vision deprivation or abnormal binocular interaction, where no signs of organic disease can be detected by physical examination of the eye and which in appropriate cases is reversible by therapeutic measures (see also chapter VI).

Amblyopia can be successfully treated up to approximately the age of 8 years, provided the obstacle to normal form vision is removed, correct optical correction is provided, and occlusion of the good eye is introduced to train the amblyopic eye. An alternative treatment to occlusion is to use cycloplegic eye drops usually atropine in the good eye, a method that has attracted renewed popularity in the United States, despite the disadvantages with the different side effects. A contact lens to decrease the vision in the good eye can be used if other methods fail. Improved vision in amblyopia with pharmacological treatment such as levodopa and citicoline has also been reported (Leguire et al. 1993, Campos & Fresina 2006).

In congenital cataract the opaque crystalline lens should be surgically removed before the age of 2-3 months to reach good visual results (see also Chapter VI).

**Methods to assess visual acuity**

Visual acuity testing in young children in a clinical setting can be divided into three subtypes according to the type of stimulus used. In detection acuity the stimulus, usually white balls in various sizes, should be detected or distinguished from the black background. In resolution acuity, the stimulus pattern, a black and white grating, should be resolved. In recognition acuity the stimulus, a letter or symbol should be recognized by the subject and identified by matching or naming.
The psychologist Fantz already in the 60’s reported that infants will prefer to look at a patterned stimulus when presented in a homogeneous field of vision. This behavioural method was called the preferential looking (PL) test. It was further developed by Teller and coworkers (1986) and brought into clinical practice. The test patterns are black and white gratings of variable spatial frequencies presented on printed cards, called the Teller Acuity Cards.

We first performed a study in adults to evaluate the method in patients with strabismic amblyopia. It was shown that grating acuity (resolution acuity) overestimates the acuity values determined with recognition tests in patients with strabismic amblyopia (Rydberg 1997).

To see how the correlation between the methods were in children, the next study was carried out in children with manifest strabismus, visual impairment due to organic eye diseases and children with normal vision. An overestimation of visual acuity was also seen in these groups of children, when grating acuity was compared with recognition acuity (Fig. 1). Hence, similar results were obtained in the children and adults.

![Figure 1. PL grating acuities plotted against the HVOT linear test in children with normal vision (circles), visual impairment (triangles) and strabismic amblyopia (squares). Each data point represents one subject, except for a few representing two subjects. The dashed line represents the line of equality between the tests. Logarithmic scales are used on both axes](image-url)
To see whether the PL test could be used as a screening test for amblyopia, the grating acuity in the amblyopic eyes and the non-amblyopic eyes were compared. In 30% of the subjects resolution acuity determined with PL was the same in both eyes, and the amblyopia would consequently have been missed if the PL test had been used in visual assessment (Fig. 2).

Figure 2. PL-grating acuities in the amblyopic eyes, plotted against PL acuities in the non-amblyopic eyes, in the adult patients with strabismic amblyopia (n=28). Each point represents one patient. The dashed line represents the line of equality between the tests and the solid line marks the limit for one octave difference between PL-acuity in normal and amblyopic eyes. Linear scales are used on both axes.

There are some Swedish studies on the development of recognition visual acuity using tests with different kinds of optotypes. Lithander (1997) found a mean visual acuity of 0.48, with the O-test (single symbols for near), in children 24-29 months old. With the KOLT test for linear acuity, a visual acuity level of 0.55 was found in children aged 30-35 months, 0.67 in children of 36-41 months and 0.77 in children 42-48 months old. Rydberg et al. (1998) found a visual acuity of 0.67 with the LH-line test and 0.6 with the HVOT-test in children 29-41 months old and 0.99 with both tests at 48-83 months (median age 51 months). In a study by Larsson et al. (2005), 81.6% of the control subjects had a recognition visual acuity of 1.33 or more at the age of 10 years.
The crowding phenomenon
Crowding also called “separation difficulty” is the inability to discriminate letters and symbols that are presented closely together, as optotypes in a line. Visual acuity determined with single optotypes is usually much better than line acuity. Crowding phenomenon is present to a small extent in normal eyes of young children, and is common in strabismic amblyopia and also in children with cerebral visual impairment (Pike et al. 1994, Jacobson et al. 1996).

Different tests assess different types of visual acuity
Different acuity values are often obtained in the same child with the different tests.

For example a child with visual impairment can sometimes detect a small pearl of 0.2 cm at a distance of 3 meters. The grating acuity (resolution acuity) can be as high as 15 cycles per degree corresponding to a Snellen visual acuity of 0.5. The recognition acuity with single letters could be 0.3, whereas the recognition acuity with linear optotypes only is 0.1, due to crowding. Detection and grating acuity do not correspond to Snellen acuity, and therefore grating acuity should always be recorded in cycles per degree, and in measuring detection acuity the size of the object and the distance used should always be recorded. The discrepancies between the tests have to be kept in mind so that the acuity values are not misinterpreted.

It is important to have reliable methods to detect subnormal vision at an early age to be able to start the treatment and habilitation. However, there are still no tests available to get reliable values when assessing vision in young children. It is not until the age of 3 ½ to 4 when children can be tested with optotypes (symbols and letters) in a line that reliable responses can be obtained (Rydberg et al. 1999).

Contrast sensitivity testing
Visual acuity represents only one aspect of visual capacity. Acuity is estimated as the smallest stimulus that can be detected at a high contrast level. However, most objects in everyday visual environment are larger than objects used in visual acuity testing and usually appear at a lower contrast. Contrast is defined as the difference in luminance between adjacent areas in a stimulus pattern. In determining the Contrast Sensitivity Function (CSF) gratings, symbols or
letters can be used at different spatial frequencies or sizes and at different contrast levels. A bell shaped CSF curve is obtained with a peak of maximum sensitivity at 3-5 cycles per degree (Fig 3). The cut-off spatial frequency is the highest spatial frequency that can be resolved at maximum contrast and also represents the visual acuity value. This value is normally 30-60 cycles per degree. There are many different tests to assess contrast sensitivity. Some tests include patterns of different contrast values but only at one spatial frequency. Other tests use patterns at only one contrast level but with many spatial frequencies (Rydberg et al.1997). For a description of the whole CSF, different spatial frequencies at different contrast sensitivity levels should be tested. The normal contrast sensitivity function in young children is lower than in adults and the function increases with age, as shown in figure 3. Contrast sensitivity measurements may reveal changes and loss of visual function that is not detected when testing visual acuity.

Figure 3. CSF for normal adult subjects (thick solid line) and in comparison with CSF for children at different ages (dashed lines) and older subjects (thin solid lines). (From Abrahamsson & Sjöstrand 1992)
**Sweep-VEP (Visual Evoked Potentials)**

An electrophysiological method was introduced for objective assessment of vision in children by Norcia & Tyler (1985). In this so called sweep-VEP method, the test patterns are sinusoidal gratings and the visual evoked potentials (VEP) to the pattern stimulation are recorded with surface electrodes placed on the occipital part of the scalp. The spatial frequency of the grating changes gradually in a sweep from 32 to 2 cycles per degree. The pattern is presented in an on-off or a pattern reversal mode, with such a high temporal frequency that a “steady state” response is obtained. The VEP amplitude is plotted against spatial frequency of the stimulus, and the visual acuity value can be extrapolated from the curve.

Sweep-VEP could be a suitable method to assess vision in young children. We have tested fifty normal subjects age 6 months-50 years (Rydberg et al. 2008). Sweep-VEP gave mostly reliable results in adults. Good test-retest reliability was obtained in 5 adult patients who were tested twice. In the younger children the results were more variable and sometimes difficult to interpret. One possible explanation is poor fixation of the stimulus pattern. If fixation could be controlled, sweep-VEP could become a valuable test to assess vision in young children in a clinical setting. More research will be performed in this area in the future.

**Conclusions**

Reliable visual acuity measurements in children can be obtained at about the age of 3 ½-4 years, when visual acuity can be assessed with a recognition test using letters or symbols in a line. Detection and resolution acuities overestimates the acuity values and different acuity values are usually obtained with the different tests. The existing methods for clinical testing of children under the age of 2 years are limited. Sweep-VEP could become a suitable test to assess vision in young children.

**References**


