Introduction

Ocular motility, i.e. the ability to move the eyes is very important for humans to have a good visual function. Our eyes are equipped with a fovea, i.e. the area of the retina with the highest visual acuity. Since this fovea represents only about a degree of the visual field we only have a high visual acuity in a very limited part of the visual field. Therefore we need to move the eyes in order to keep the visual surroundings updated. To do so it is required that the eyes are able to i) keep a steady fixation on a stationary target of visual interest, ii) keep a steady fixation although the target is moving, iii) move the eyes precisely to different parts of the visual field and iv) have a well developed eye alignment and avoid double vision.

Eye movements of different types are required for these specific functions, and they are controlled by different areas of the brain and the brain stem. The separate types normally mature during different stages of child development. Therefore studies of the development of the eye movement types can bring information about the maturity of the specific brain region from which it is generated and also help in diagnosing and following diseases in the brain and brainstem.

Visual Fixation

Visual fixation is the ability to hold the eyes stable on a stationary target both when the head and body are stationary as well as when in motion. This is crucial for the good visual function since as stated above the visual acuity is highest within only a very small part of the visual
field. A stable fixation is usually interrupted by several involuntary eye movements such as micro tremor, visual drift, and micro saccades and blinks (Fig. 1).

Figure 1. Ten seconds recording of a ten year old child fixating a stationary target on a computer screen. Note the presence of micro saccades, drifts and tremor.

It was recently shown that the ability to keep a steady fixation on a stationary target matures with age and that this ability does not reach adult values until in the teens (Fig. 2).

A stable fixation is also required when the head and body are moving. Since humans are in motion most of the time we need an effective reflex to obtain a stable view of the visual surroundings. Two reflexes, both initiated in the balance organ in the inner ear serve this function. The VOR, i.e. the vestibulo-ocular reflex originates in the semicircular canals of the vestibular apparatus in the inner ear. The semicircular canals detect rotational forces in all directions. The signals from them help keep the eyes on a target by inducing eye movements that compensate for body and/or head movements. This ability develops early in childhood and a well functioning VOR can be seen already at a few days of age.
Figure 2. Histograms showing increased fixational stability by lesser number of intruding saccades during fixation. Note also that the number of blinks during fixation is almost similar between the different age groups. Group A1 represent children 4-7 years, A2 6-9 years, A3 9-12 years and A4 12-15 years.

When the human body rotates with larger amplitude the VOR cannot compensate fully for the rotation since the amplitude response of the reflex is limited. Instead the OKN, i.e. the optokinetic reflex keeps the eyes on a target when the body is rotating or the visual scene is moving with larger amplitude. An example is when being on a train and looking out of the window. The image of the world outside is moving and in order to get a detailed view of a target, the eyes have to follow it. When the eyes reach a certain deviation and viewing sideways becomes inconvenient, the eyes move rapidly towards the straight ahead position to fixate on a new target and then follow it. In doing so fixation and good vision is maintained on targets of interest, although the surrounding is moving. The sequence of following eye movements and rapid re-fixations is the OKN. The same reflex is effective when we view the surroundings sitting on a rotating chair. The OKN is quite a primitive reflex and it develops early. However, during the first months of life directional asymmetries have been observed. When testing the monocular OKN, the temporal-nasal directed OKN is seen to be developed earlier than the nasal-temporal OKN. Normal OKN is not developed until about a year of age. In subjects with early childhood strabismus this directional asymmetry is known to persist throughout life.
Saccadic system

As stated above, the area of a good visual acuity is corresponding to only about a degree of the visual field and in order to view a larger visual scene we need to move our eyes to fixate different parts of interest. These eye movements, called saccades, are used both spontaneously as well as voluntary in all our daily activities. When reading for example, the line of sight is not moved continuously over the text but instead in small jumps, saccades, between different parts of fixation in the text. The amplitude of saccadic movements and the duration of the fixation periods depend on the complexity of the text and the reading comprehension. It is known that the more difficult the text, the shorter are the saccadic jumps between points of fixation. It is also known that the beginner reader makes smaller saccades and longer fixations on the different words before acquiring an adult reading performance (Fig. 3).

Figure 3. Increased fixational stability by more central fixation with increasing age. For explanation of procedure see text. Same age groups as fig 2.

The saccadic system has to be trained to mature. There are two fundamental differences between mature saccadic performance and saccades performed by a child. Firstly, it is known that the latency to initiate a saccade is about 200 msec in the adult whereas in the child the latency can be much longer. The saccadic latency in a preschool child is usually about 400 msec, i.e. twice the adult value (Fig. 4). The system matures with age and adult values for saccadic latencies will be reached at about the age of school start or even later. The other difference between a child and an adult regarding saccadic development is that the child
usually makes multi-step saccades. Since the saccadic system is still immature, the ability of a child to adequately calculate the exact amplitude of a saccade is not yet developed. Thus the child will make several saccadic steps when trying to reach a target within the visual scene (Fig. 4). Also this function matures with age (and training) and adult values are probably reached by the early teens. Children with neurological disease such as Ataxia teleangiectasia will never reach adult values and they show also in the teens extremely long saccadic latencies.

**Figure 4.** Reading eye movements in a normal 10 year old child (left) and a Dyslexic 10 year old (right). Same time scale in both figures. Note that the normal child performs better reading eye movements with two lines completed during the recording while the Dyslexic child during the same time has almost only completed reading of one line of text due to longer fixations and shorter reading saccades.

**Smooth pursuit eye movements**

In order to keep a moving target in a visual scene on the foveal area representing best vision, we need to track the target. The eye movements that serve this function are the smooth pursuit movements. The ability to exactly track the moving object requires practice to get well
calibrated. This ability to perform adequate smooth pursuit movements develops with the maturation of the fovea and visual acuity, since a good vision is needed to be able to see the target and to track it. During the period of fovea development and subnormal visual acuity, small children often exhibit a cogwheel tracking, i.e. a tracking consisting of with small saccades instead of a smooth pursuit movement. This type of tracking is represented by a very low so called smooth pursuit gain, i.e. the ratio between eye position and target position is below normal. The smooth pursuit gain in adults usually is close to 1.0, meaning that the eye is tracking the target almost perfectly. The pursuit gain in children can be as low as 0.6, which means that the eyes are directed exactly at the target only 60% of the time trying to track it. The adult smooth pursuit gain is probably reached at early teenage.

Vergence eye movements

The vergence eye movements are used for tracking targets in depth and for keeping the eyes aligned. Vergence eye movements depend on the maturation of the fovea and visual acuity function as does the smooth pursuit movements. The first months of life when the fovea starts to mature and the visual acuity increases, is also the time when accommodation begins to function and the vergence eye movements start to develop. A full convergence response to a near target can be seen already in a 2 months old baby (figure 5).

Figure 5. Vergence in a two-month old child.
However, the other vergence functions are not fully developed at this early age. Deviations of eye position can be seen in infants both in the horizontal and the vertical directions. Even if vergence positions stabilize during the first couple of years, they are probably not mature until the early teens (Fig. 6).

**Figure 6.** Histograms showing the increased fixational stability in terms of horizontal and vertical vergence positional SD with increasing age. Both the horizontal as well as the vertical vergence stability increases.

**Conclusions**

The different eye movement systems mature at different times of child development. Some systems parallel the maturation of the visual acuity function as the smooth pursuit system and the vergence eye movements. On the other hand, some eye movement systems seem to be independent of the visual maturation such as the VOR and OKN, and they are functioning already soon after birth. It is therefore important when examining a child to take all the different eye movements systems into consideration and after a thorough clinical investigation draw conclusions if the child has a normal eye movement development or not. Several neurological, metabolic and endocrine inborn diseases include eye movement abnormalities, which must be separated from the normal development. With a careful investigation of the eye movement ability in the child such diseases can sometimes be excluded or verified.
References

