Development of gaze tracking of small and large objects

Kerstin Rosander · Claes von Hofsten

Received: 22 December 2001 / Accepted: 12 May 2002 / Published online: 26 June 2002
© Springer-Verlag 2002

Abstract A longitudinal study was designed to address the relationships between the smooth pursuit (SP) and the optokinetic response (OKR). Eye and head movements were measured in infants between 7 and 14 weeks of age. They were placed in front of a moving object subtending visual angles of 2.5, 5, 7, 14, 21, 28, and 35°. The object oscillated sinusoidally along a horizontal path with a frequency of 0.25 Hz and an amplitude of ±25° visual angle. It was found that the number of saccades was dependent on object size: at 6 and 9 weeks of age there were more saccades for the smallest objects. With increasing age, the number of saccades decreased. The composite eye movement gain (smooth tracking + saccades) did not change with age but for the 6.5-week group the gain was higher for smaller objects. The gain of the smooth eye tracking increased with age and showed no dependency on object size. In conclusion, the results do not support the concept of two separate systems, the OKR and the SP, each of them processing eye tracking of small and large objects. Finally, it was observed that two infants at 6.5 weeks of age who used considerable head movements did not inhibit the vestibular-ocular response.

Keywords Smooth pursuit · Oculomotor · Saccades · Infant · OKR

Introduction

Two kinds of tracking eye movement with different functions have been distinguished: the optokinetic response (OKR) and the smooth pursuit (SP). The OKR is generated by “wide-field” optical motion and its function is to enable stabilization of gaze while the subject is moving around. The function of SP is to enable stabilization of gaze on a small moving object within a complex visual scene regardless of motion elsewhere in the visual field. The OKR is a phylogenetically older system and is present in all mammals while the SP is only present in primates (Büttner and Büttner-Ennever 1988; Paigie 1994). It has been argued that OKR and SP are distinct systems. However, both systems have neural pathways that are rather close to each other (Krauzlis and Stone 1999) and both systems are predictive. These facts suggest that they could be regarded as parts of one highly versatile system rather than two distinct ones.

If OKR and SP were distinct systems, it would be expected that the phylogenetically older OKR would develop ahead of the SP. This hypothesis has received some support from studies of eye movements in early infancy. Some tracking ability is present in the neonate but for targets of limited size it seems to be primarily saccadic. Dayton and Jones (1964) found that neonates pursued a wide angle visual display with smooth eye movements but the pursuit became rather jerky for a “small” target. Kremenitzer et al. (1979) found that neonates would smoothly track a 12° black circle, however with low gain and only approximately 15% of the time. Roucoux et al. (1983) using a big black circle covering 10° of visual angle found evidence of SP in 1-month-old infants, but only at low velocities and with low gain. Bloch and Carchon (1992) used a red transparent ball covering 4° of visual angle and found only saccadic tracking in neonates. Similar findings were reported by Aslin (1981) who used a black bar 2° wide and 8° high moving sinusoidally in a horizontal path. He found only saccadic following of the target up to 6 weeks of age after which SP started to be observed. Phillips et al. (1997) measured SP for different object velocities in 1- to 4-month-old infants. They found that for an interval of 8–32°/s consistent smooth pursuit was observed although interrupted with saccades.

The low gain tracking of large targets and the inability to smoothly track small ones is not caused by immaturities in the oculomotor system itself. The gain of vestibularly controlled smooth eye movements approaches unity under some conditions (Finocchio et al. 1991;
Rosander and von Hofsten 2000). Therefore it can be concluded that the immaturity is only confined to the visual mode of control. Furthermore, the studies of very young infants indicate that the size of the visual target is an important determinant of the smoothness of tracking, smaller targets elicit more saccadic tracking.

Around 2–3 months of age, SP shows significant improvements (Aslin 1981; von Hofsten and Rosander 1997; Phillips et al. 1997; Richards and Holley 1999). von Hofsten and Rosander (1997) studied longitudinally the smooth tracking of a 10° target moving with different amplitudes, speeds, and motion functions and found that both gain and timing improved in a very rapid and consistent way over conditions from 2 months of age. However, such improvements were also observed when the motion occupied the whole visual field (von Hofsten and Rosander 1996; Rosander and von Hofsten 2000).

Although the cited studies suggest that smooth tracking of large targets develops ahead of that of small ones, they also show that these two developments share common features. The aim of the present study was to resolve the question of whether one or two mechanisms are necessary to account for the development of smooth tracking. If there are two mechanisms and they have different developmental histories, it should be possible to separate them by studying the effect of object size on the development of smooth eye tracking. If one mechanism specialized on stabilizing gaze on large stimuli (OKR) is present at birth and one specialized on stabilizing gaze on small objects (SP) develops around 2–3 months of age, infants below that age should track large stimuli significantly smoother than small ones. As the SP system develops the difference in performance between large and small objects should diminish. If on the other hand there is one developing system responsible for the smooth tracking of both large and small objects, performance should improve with age but not differ as a function of object size.

Infants were studied longitudinally between 6 and 15 weeks of age, as this interval well covers the critical and fast development of SP. In designing the experiment, the question arises what range of target sizes includes both typical SP and OKR stimuli. Heinen and Watamaniuk (1996) suggested 30° of visual angle and larger to act as “traditional” OKR stimuli in adults. Therefore, we included objects ranging from 2.5° (the smallest object possible with the experimental setup) to 35°. All objects oscillated sinusoidally according to a horizontal path with an amplitude of 20° and a frequency of 0.25 Hz. This motion design has earlier been shown to produce good tracking with maintained interest in the object (von Hofsten and Rosander 1996, 1997).

The following questions were asked. Does object size have a systematic effect on tracking gain? If so, is the effect of object size greater at ages below 2 months when the SP system is undeveloped? If there is such an effect of object size, does it diminish with the development of SP as suggested by the two-mechanism hypothesis? Similar questions were asked regarding the difference in time between pursuit and object during tracking, the pursuit lag. Is pursuit lag related to object size in young infants? Does such a relationship change with the emergence of SP? von Hofsten and Rosander (1996) found that the tracking of a wide-field object at 4 weeks of age was associated with a lag of about 180 ms but that it had diminished to 60–70 ms at 2 months of age. Such a lag was also found for 9-week-old infants tracking a 10° object (von Hofsten and Rosander 1997). There are no data, however, on the lags for smaller objects at ages below 2 months.

**Materials and methods**

**Subjects**

Nine infants participated, four girls and five boys. They were seen longitudinally at 6.5±0.5, 9±0.1, 12, and 14.5±0.5 weeks. Two of the subjects could not come at 9 weeks, one could not come at 12 weeks, and two could not come at 14.5 weeks. All infants were full term. The study was approved by the ethics committee at the Research Council in the Humanities and Social Sciences and was therefore performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Before the first session, the parents were informed about the experiment and its purpose. They signed a consent form of participation.

**Apparatus**

The apparatus used has earlier been described in detail (von Hofsten and Rosander 1996, 1997, Rosander and von Hofsten 2000). The infant was placed in an infant chair, especially designed to give full support of the trunk, while allowing free movements of the limbs. It was placed at the center of a cylinder, 1 m in diameter and 1 m high. The rotation axis of the cylinder corresponded approximately to the dorsal column of the infant. The head of the subject was lightly supported with pads so that it could rotate without falling aside. During the experiments, the chair was comfortably inclined at an angle of 40°.

The inside of the cylinder was homogeneously white. In front of the subject a stimulus, an object in the form of a happy face, was

![Fig. 1 Two of the objects, 7 and 28°, respectively](image)