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Vertical and horizontal smooth pursuit eye movements in children: A neuro-developmental study

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ABSTRACT

An evaluation of eye movements is very useful in neurological disorders but is complicated by issues such as maturation and lack of normative data in children. In order to address these issues we studied smooth pursuit eye movements of 65 normal children aged 7–11 years old. The gain of horizontal smooth pursuit (HSP) was higher than the gain of the vertical smooth pursuit (SP) and this difference had a statistical tendency to disappear with aging from 7 to 11 years. These data suggest that, in the cerebral regions involved in the control of SP, i.e. posterior parietal and superior temporal lobe regions, the networks for VSP mature latter than those for HSP.

1. Introduction

Visual function has sensory and motor components, and exploration of surrounding space requires normal visual acuity and also normal ocular gaze which requires smooth pursuits and saccades.[2] Asymmetry between vertical and horizontal eye movements is well known and is related to the fact that different brain structures drive both movements.[1,2] In a preliminary study that we carried out in 2003 in children with developmental coordination disorder (DCD) such as dyspraxia, there was a significant number of children with DCD who had saccadic horizontal smooth pursuit (SP) and frequently vertical saccadic SP. It appeared that vertical SP of children with DCD was impaired more often than that of the

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normal population. These data formed the rationale of the present study to gather normative data in children from 7 and 11 years old.

Furthermore, there is a previously described asymmetry between horizontal and vertical tracking mechanisms, but the developmental origins of this asymmetry are not well understood.[6,2] Few studies have explored vertical tracking in children. In 1999, Richards and Holley[7] studied 8- to 26-week-old infants and found that horizontal tracking was more developed than vertical tracking at this period of development. In a recent 2006 study, Rutsche and co-authors[13] analyzed the development of visual horizontal SP and vertical SP with photo-oculography but only in the first 6 years of life. The aim of their study was to establish normative values. They showed that attention time increased with increasing age and decreased with increasing stimulus velocities. The ratio between time of SP and time of SP plus saccades increased with increasing age and for velocities of 15°degrees/s and 30°/s; gains for horizontal movements were larger than that for vertical movements. In 2003, also in children from 9 to 11 years old, Takeichi et al.[15] found that vertical SP was less developed than horizontal SP. More recently, Salman et al.[14] have also concluded that horizontal and vertical gains improve with age and approach adult values in mid-adolescence. The vertical SP is normal in adults when the vertical test is performed on 20° (as in our study).[6]

During childhood, maturation of the oculomotor system can be easily explored with a simple and low-cost method: motor electro-oculography (EOG). The aim of the present study is to explore the maturation of horizontal SP and vertical SP in children lacking any developmental delay and without ophthalmologic or neurological pathology in order to establish normative data required to analyze gaze movements in children with learning disabilities[8–12] and to reach more precise conclusions regarding the impairment of the pursuit systems (horizontal and vertical) in learning disabilities such as DCD.[5]

2. Methods

2.1. Participants

Sixty-five school-age children (36 females, 29 males) in the age range from 7 to 11 years were selected from a French elementary school in Paris. Authorization was given by the Academy. A consent form was signed by each parent. Inclusion criteria for recording of eye movements included healthy children without history of ophthalmologic disease, learning disability, or skin allergies. School health records were reviewed with the participation of the school's medical officers. All children had to have academic achievement commensurate with their age. Exclusion criteria included any sensory, perceptual, motor or language impairment and learning disabilities, refractive error, or any medical illness.

2.2. Apparatus and visual stimuli

The test was carried out in a quiet environment and the child was carefully instructed. The Metrovision© (59840 Perenchies, France) apparatus was used for stimulation and recording. ECO 10 skin electrodes provided by Metrovision© (59840 Perenchies, France) were used. Nine electrodes were attached: 4 per eye and the ground electrode. The skin was carefully cleansed. An abrasive paste was used to ensure skin impedance at about 3 kΩ. The electrodes themselves contained a conductive paste. For vertical eye movement testing the infra-orbital electrode was placed within 1 cm of the inferior eyelid margin in the midline; the superior electrode was located adjacent to the superior orbital edge, also midline. Horizontal electrodes were located 1 cm away from the outer and inner canthi, respectively. The ground electrode was placed on the forehead. Recording began 10 min after the electrodes were attached. The band-pass of the amplifiers was 1–35 Hz. The input impedance of the amplifiers was 1000 GΩ. Bioelectric signals were pre-amplified, amplified, and digitized. The data were recorded and analyzed with a PC with dedicated software from Metrovision© Company. Electro-oculography was performed to record ocular movements in all children using the same protocol. During the procedure, the child was comfortably seated and his or her head rested on a head restraint. All the children were given clear instructions about the tasks to be performed. Standard procedures were followed to encourage and ensure comfort, continued attention, and motivation.

2.3. Design and procedure

Spontaneous movements during ocular fixation were first recorded. Then, horizontal smooth pursuit was recorded by asking the child to follow a target that moved on a display screen with a horizontal 1-D sinusoidal motion with an amplitude of 40° and a speed of 30°/s. Vertical smooth pursuit was recorded in the same way asking the child to follow the target moving vertically with an amplitude of 30° and speed of 30°/s. The screen was 30 cm from the forehead. Each stimulus was presented twice. Each trial lasted 20 s. There was a 5–10 s pause between stimuli. A short break occurred if the child lost concentration. If the child became inattentive during a trial, that trial was presented again at the end of the experiment. The entire experiment lasted 10–15 min.

2.4. Data analysis

The eye movements were calibrated by adjusting their measured amplitude to the amplitude of the target motion. The gains of the horizontal and the vertical pursuits were automatically calculated by software in the PC. These data were tabulated for horizontal SP and vertical SP. To compare horizontal and vertical pursuit gains, the ratio between horizontal gain and vertical gain was calculated (HP gain/VP gain) and the relation between ages at this ratio was statistically analyzed using the Spearman's rho correlation coefficient.

3. Results

In our cohort, 65 children aged from 6.25 to 11.75 years (mean: 8.73, median: 8.75 and standard deviation: 1.49) were studied. Age was not normally distributed in our sample. Horizontal pursuit could be analyzed in all children, whereas vertical pursuit could be analyzed in only 64 children (one case aged 9 showed a high noise level on the recordings). The horizontal pursuit gain ranged from 39.5% to 100% (mean: 76.86, median: 77.75 and standard deviation: 14.54). The vertical pursuit gain ranged from 35% to 97% (mean: 66.43, median: 65 and standard deviation: 15.38). The horizontal gain/vertical gain ratio ranged from 0.44 to 1.69 (mean: 0.88, median: 0.86 and standard deviation: 0.22).

The statistical analysis did not show any significant correlation of horizontal pursuit gain (Fig. 1) or of vertical pursuit gain (Fig. 2) with age. But there is a statistical tendency, evident in the figure that the regression trace of the ratio between vertical and horizontal gains approaches 1 (Fig. 3) (i.e., with increasing age, there is less and less difference between the two gains).

The statistical analysis showed that when the horizontal gain increases the vertical gain also increases ($p < 0.001$) (Fig. 4). The statistical analysis also showed that the horizontal pursuit gain reaches 1 quickly while the vertical pursuit gain is more variable.

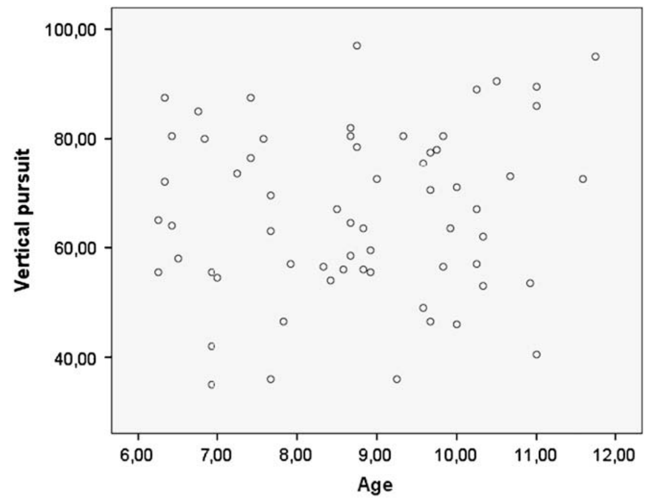

Fig. 2 – Scatter plots of mean vertical smooth pursuit (VSP) gain of each participant and age in years. Gain increases with age (Spearman's rho = 0.088: p = 0.493).

4. Discussion

A functional visual system requires versatile eye and head movements in both the horizontal and vertical planes of the visual field.[2] Two kinds of eye movements make this possible: saccades and SP.[2] When SP is insufficient to track a moving target, catch-up saccades are employed to recapture it.[2] In a preliminary study[3] we observed that children with dyspraxia frequently demonstrate saccadic horizontal and/or vertical SP. We sought to establish normative data for children employing identical methods we used for children with DCD, namely by EOG recording. Since the diagnosis of DCD is typically established between ages 7 and 11 years, our study has included only children without any medical problem in this age group. Our results show that horizontal SP in our sample is in the normal range of adults. This finding confirms that horizontal SP is already mature by 7 years of age. Vertical SP is abnormal in most children between ages 7 and 11 years, whereas it is normal in average adults. Maturation would therefore occur after the age of 11. Therefore, it is suggested that maturation of vertical SP occurs after the maturation of horizontal SP (established by the age of 8 years). These results substantiate the developmental asymmetry between horizontal and vertical eye movements already found in previous studies.[6,15,2] One third of children in the 7–11 year-old group had normal vertical SP. Thus it could be interesting to compare this subgroup of children with children who have known neurological disorders in whom abnormalities of vertical SP are thought to occur. Horizontal SP could also be studied and assumed to be abnormal in those pathological cases, as it is normal in healthy children. Our results agree

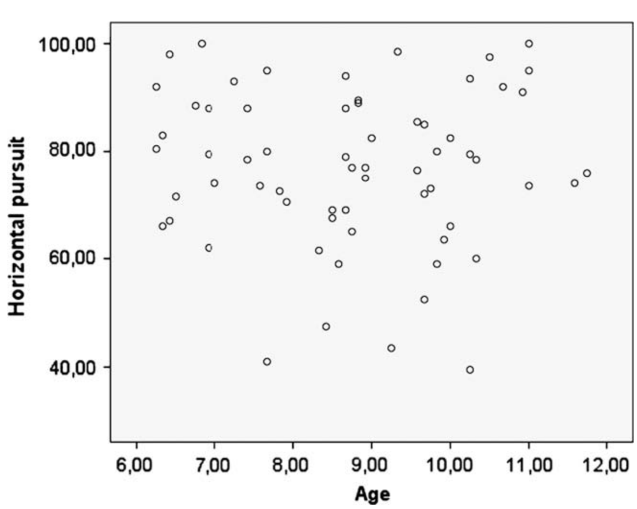

Fig. 1 – Scatter plots of mean horizontal smooth pursuit (HSP) gain of each participant and age in years. Gain increases with age (Spearman's rho 0.002; p = 0.989).

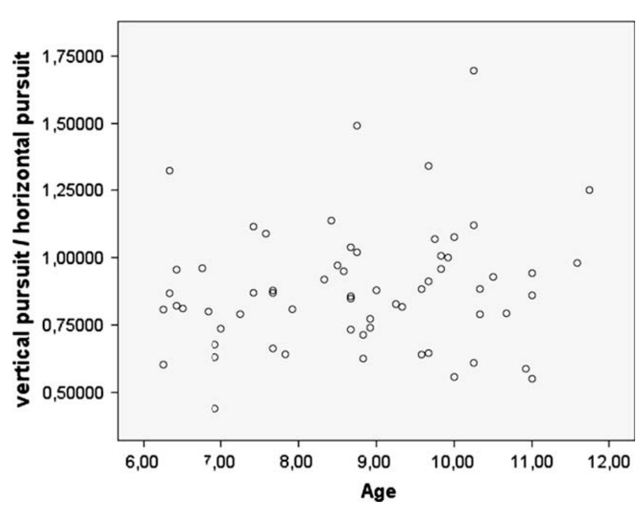

Fig. 3 – Scatter plots of the ratio between the mean vertical smooth pursuit (VSP) gain and the mean horizontal smooth pursuit (HSP) gain of each participant and age in years. Gain increases with age (Spearman's rho = 0.125; p = 0.329).

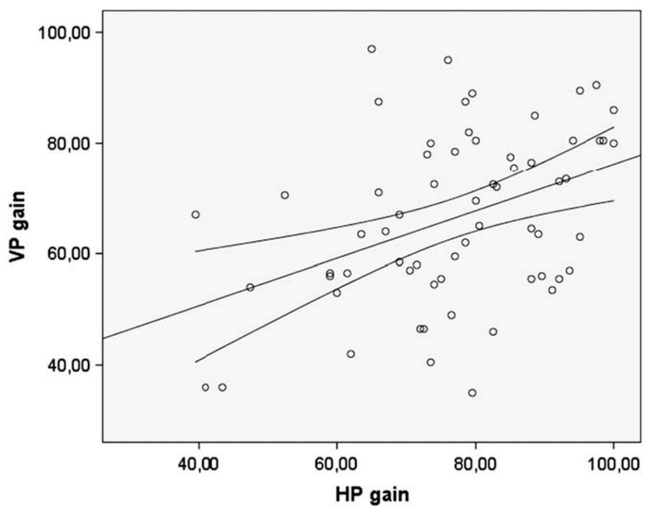

Fig. 4 – VP gain versus HP gain. When HP gain increases, VP also increases ($p < 0.001$).

with the 1998 study by Katsanis et al.[4] regarding the development of oculomotor function in preadolescence, adolescence, and adulthood. These authors examined developmental differences in SP in a large sample of preadolescent, adolescent, and adult males. Examination of age effects indicated that, by late adolescence, the smooth pursuit system reaches adult levels of functioning. No significant differences were found between the adolescent and adult groups on most global measures. However, both groups had better eye tracking than the preadolescent group, suggesting that during preadolescence the oculomotor system is still developing and is not yet capable of optimal performance. Our study confirms the maturation asymmetry between horizontal SP and vertical SP: vertical SP maturation is accomplished in late adolescence, after 11 years old and before adulthood.[15,2] In the study by Salman et al.,[14] age range is narrower (from 6.25 to 11.75 years old compared to 8–19 years old for Salman's study), our number of participants is greater (65 and 38 subjects in Salman's study) and our mean age is much more lower (8.73 and 13 in Salman's study). The difference in age in the two studies is a very important difference because it is now believed that maturation of eye movements, particularly of the vertical movements, is completed during the preadolescence period. On the other hand, in Salman's study the visual target moved at $\pm 10^\circ$ amplitude and in our work horizontal target displacement is greater ($\pm 20^\circ$) and the method for recording smooth pursuit is different (infrared method in Salman's study). Despite these differences, our results are consistent with those of Salman's and confirm them in a larger group of younger children.

It would be also interesting to increase the total number of subjects to compare the results between males and females to determine whether there is an effect of gender on the maturation of the oculomotor system. In a 1993 study by Ross et al.,[8] the gender of subjects was found to have no effect on any eye movement variable. It would also be useful to compare the results of the present study with the VP and HP indexes obtained in a young adult group (from 18 to 25 years old) to determine whether oculomotor-system maturation is completed between 11 and 18 years old. Furthermore, because it is well known that the SP system involves posterior parietal and superior temporal lobe regions,[8] the present data suggest that the brain networks involved in vertical SP mature later than those involved in horizontal SP. The cerebellum and the brainstem are likely involved in this maturation processes.

In conclusion, our study provides normative values for horizontal SP and vertical SP in healthy children between ages 7 and 11 years. This EOG method is very simple, non-invasive, inexpensive, and quantitative and can be easily performed in young children. Recent studies on eye movements have used the infrared method which is much more accurate but also very expensive and sometimes not so easy to perform in young children. The cost of the infrared instrumentation and the difficulty to use it in children were factors in our decision to use the classical method of EOG. In future studies it would be useful to compare the two techniques directly in the same subjects. Nevertheless, the EOG method allowed us to confirm that the development of pursuit in children is asymmetric: horizontal SP is mature by the age of 7, whereas the maturation of vertical SP is not completed by the age of 11. Furthermore, this method has the advantage of establishing an objective index representing the quality of the pursuit. Thus, the index obtained in a child with, for example, a DCD, could be compared with the normative data of the subjects of the same age. So, this normative database of SP gain in a group of children aged from 6.25 to 11.75 years old is very useful for detection of impairments, the evaluation of oculomotor abnormalities in school-age children with developmental coordination disorder or learning disabilities and eventually the comparison of the efficiency of therapy.

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