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Binocular coordination of saccades during reading in children with clinically assessed poor vergence capabilities

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ABSTRACT

Prior studies have pointed toward a link between the saccadic and vergence systems, coordinating binocular saccadic movements. Recent studies have shown that vergence deficits in children induce poor binocular coordination during saccades, but none of them have studied ocular motility in children during a daily task such as reading. The present study tests whether vergence deficits in children perturb binocular coordination of saccades and fixation during reading. Our second objective was to explore whether vergence training could improve the quality of binocular coordination. Twelve patients (from 7.3 to 13.4 years old) complaining from vertigo but without vestibular and neurological pathology underwent orthoptic tests and were selected for our study when they presented vergence deficits. Eye movements were recorded during a reading task with a Mobile EyeBrain® Tracker video-oculography system. Data were compared to twelve age-matched controls with normal orthoptic values. While there was no statistically significant difference in saccade amplitudes between the two groups ($p = 0.29$), patients showed higher disconjugacy during and after the saccades compared to controls ($p < 0.001$). After orthoptic training, six patients out of the first 12 examined came back for a second oculomotor test. All showed a significant improvement of their binocular saccade coordination. We suggest that the larger disconjugacy during reading observed in patients before training could be due to poor vergence as initially assessed by orthoptic examination. Such findings support the hypothesis of a tight relationship between the saccadic and vergence systems for controlling the binocular coordination of saccades. The improvement reported after orthoptic training is in line with the hypothesis of an adaptative interaction on a premotor level between the saccadic and vergence system.

1. Introduction

Reading, a daily task in modern society, requires several eye movements including saccades and vergence, which must be well coordinated. Horizontal saccades bring the eyes to successive words and are followed by fixations on each word to allow linguistic processing. The vergence angle between the two eyes must be well adjusted at the distance of the word for appropriate fusion of the two retinal images (Jainta, Jaschinski, & Wilkins, 2010). Without such coordination between the saccadic and vergence systems, reading may be compromised, and this, to our knowledge, has never been examined in children.

Collewijn, Erkelens, and Steinman (1988) first described human horizontal saccade characteristics. They reported a vergence-saccade coupling in healthy adults during voluntary saccades towards LED-targets. This coupling included a divergent disconjugacy during the saccade, followed by a convergent disconjugacy during the post saccadic fixation period. Such disconjugacy is most likely due to the fact that the abducting eye makes a larger movement than the adducting eye during horizontal saccades. Lewis et al. (1995) also proposed the existence of a link between the saccadic and vergence systems in adult patients with trochlear nerve paresis. After surgery, clinical assessment showed in those patients an improvement in vergence amplitude and a better binocular coordination of vertical saccades.

Fioravanti, Inchingolo, and Spanio (1995) was the first to investigate the development of binocular coordination in children by recording horizontal saccades to LED-targets. They compared saccade characteristics between 3 groups of subjects: young children of 5–9 years old, older children of 11–13 years old and adults. The authors found similar oculomotor behavior between the older children and the adults, that is, the typical pattern divergent disconjugacy during the saccade followed by convergent disconjugacy during the post-saccadic fixation period. In contrast, children

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5–9 years old made larger saccade with the adducting eye than the abducting one. The adducting eye also presented a shorter duration of the acceleration phase and a larger peak velocity. Surprisingly, in this younger group of children, the disconjugacy during the saccade was convergent. The authors attributed this effect to a "poor compensation of mechanical asymmetries of the orbital planes existing in young children". Later, Yang and Kapoula (2003) studied the binocular coordination of saccades to LED targets at two distances (20 cm and 150 cm) in children (4.5–12 years old) and adults (22–44 years old). They confirmed that the binocular coordination of children was poorer than adults' both during and after the saccades, especially in younger children (4.5–6 years of age). However, they showed that the disconjugacy during the saccades depended on target distance only in children (with larger disconjugacy for near targets) but not in adults. They also showed that disconjugacy of saccades improves with age and reach adult values around 10–12 years. The authors attributed these results to a maturation of cortical or subcortical structures responsible for saccade and vergence control and not to a mechanical reason since the dynamic of the saccades (peak velocity) did not differ between the adults and the children, nor with distance.

Studies of children's binocular motor coordination during reading are rather rare, in spite of the fact that this task requires saccade and vergence coupling. A study from our group (Bucci & Kapoula, 2006) compared binocular coordination in a "single word reading" task between two groups of healthy subjects: seven-year old children and adults. They found that binocular coordination during and after the saccades was poorer in children than in adults and characterized by greater disconjugacy. The authors advanced the hypothesis that the poor quality of binocular coordination of saccades could be related to immaturity of normal oculomotor mechanisms responsible for fine control between the saccadic and vergence commands. Such mechanisms could develop with visual experience during daily life and be associated with maturation of the cortical control of saccadic eye movements during childhood (Luna et al., 2001).

Bassou et al. (1992) were the first to explore the binocular coordination of saccades in reading in a study of ten-year old children. They used an EOG recording system providing low resolution eye movement measurements. These authors found poor binocular coordination in children and suggested that Hering's law (that the eyes are well coupled because the oculomotor muscles receive equal innervation) does not always apply in reading. Unequal innervations could lead to disconjugate eye movements, resulting in reading difficulties. Blythe et al. (2006) compared the binocular coordination of eye movements in reading, in twelve normal children aged from 7 to 11 years old and twelve young adult subjects (18–21 years old). They found that the disconjugacy at the beginning and at the end of the fixation was significantly greater in children than in adults. They also reported that children more frequently diverge during saccade and converge during post-saccadic fixation, and that this behavior changes over childhood to the adult pattern.

All of these studies show that adult saccadic and vergence interaction, necessary for a good binocular coordination during and after the saccades, is still developing in children under the age of 12. These results suggest also that a deficit in vergence or saccade oculomotor systems could lead to poor binocular coordination. In our previous work (Bucci et al., 2006), we compared the binocular coordination of saccades to LEDs at near (30 cm) and far (150 cm) distances in a population of fifteen children (from 10 to 15 years) with vergence deficits. We found normal binocular saccade coordination for distant targets, but severe abnormal disconjugacy for saccades to near targets. Interestingly, this study showed also that orthoptic vergence training significantly reduced the disconjugacy of saccades at near distance. Dusek, Pierscionek, and McClelland (2011) showed clearly that orthoptic training significantly improves the characteristics of saccades and vergence in children with vergence deficiency.

In the present study, we evaluate binocular coordination during and after saccades during a text reading task, which requires a good coupling between the saccadic and vergence systems, in children with clinically assessed vergence insufficiency. Given that vergence abnormalities associated with vertigo appears to lead to poor binocular control during and after the saccade, as suggested by our previous work (Bucci et al., 2006), we make the hypothesis that such poor binocular coordination of saccades might also be observed during a reading task. Secondly, we aim to explore whether vergence training could improve the quality of binocular motor control.

2. Materials and methods

2.1. Subjects

Twelve children (mean age 10.25 ± 1.82 years, range from 7.4 to 13.8 years) participated in this study. They had been referred to the Robert Debré Paediatric Hospital in the ENT or ophthalmology departments because of vertigo, headaches and dizziness. Comprehensive testing showed normal vestibular and neurological function (Wiener-Vacher, Toupet, & Narcy, 1996) but orthoptic examination revealed vergence insufficiency. A group of twelve age-matched normal children were also recruited as controls for comparison. Patients and controls were speaking French as a first language and had no known reading difficulties. The investigation adhered to the principles of the Declaration of Helsinki and was approved by our institutional Human Experimentation Committee. Written parental consent was obtained for each subject after the nature of the experiment had been explained and understood.

2.2. Ophthalmological and orthoptic tests

2.2.1. Before oculomotor training

All children underwent classic orthoptic examination to evaluate their oculomotor function. Table 1 reports the results obtained for the patients (Table 1A) and for the control children (Table 1B). Children were selected as patients when they suffered from vertigo and headaches, and when orthoptic examination revealed abnormal values (of at least one of these parameters of the orthoptic evaluation: NPC, convergence and divergence amplitudes). The convergent and divergent amplitudes were measured with a Berens horizontal prism bar. The value of convergence and divergence amplitude corresponded to the prism value inducing a "break response". Control children were selected as normal when they did not complain of any vertigo and/or headaches, and showed normal values at the orthoptic evaluation. In the literature, normative data for orthoptic examination varied greatly (Besnard, 1973; Von Noorden, 2002; Espinasse-Berrod, 2008; Jeanrot & Jeanrot, 2003). We based our criteria on our normal values calculated in our clinical research center on a population of 81 subjects age from 5 to 17 years (mean age 9.6 ± 3 years) presenting no vertigo, no headaches, no vestibular pathology and no neurological or ophthalmologic pathology. Based on these criteria, significant differences in orthoptic examination between control and patients were only observed for the near point of convergence (NPC, evaluated with a small accommodative target) and the convergence fusional amplitude.

2.2.2. After oculomotor training

Oculomotor training consisted of 12 sessions (2 per week) of 20 min each for a total duration of 6 weeks. The training session