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Original article

Voluntary control of saccadic and smooth-pursuit eye movements in children with learning disorders

Junko Fukushima[a,*], Satoshi Tanaka[b], Jeremy D. Williams[c], Kikuro Fukushima[d]

[a]*Department of Health Sciences, Hokkaido University School of Medicine, West 5, North 12, Sapporo 060-0812, Japan*
[b]*Tokyo Metropolitan Umegaoka Hospital, Tokyo, Japan*
[c]*Rakuno Gakuen University, Hokkaido, Japan*
[d]*Department of Physiology, Hokkaido University School of Medicine, Sapporo, Japan*

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Abstract

Eye movement is crucial to humans in allowing them to aim the foveae at objects of interest. We examined the voluntary control of saccadic and smooth-pursuit eye movements in 18 subjects with learning disorders (LDs) (aged 8–16) and 22 normal controls (aged 7–15). The subjects were assigned visually guided, memory-guided, and anti-saccade tasks, and smooth-pursuit eye movements (SPEM). Although, the LD subjects showed normal results in the visually guided saccade task, they showed more errors in the memory-guided saccade task (e.g. they were unable to stop themselves reflexively looking at the cue) and longer latencies, even when they performed correctly. They also showed longer latencies than the controls in the anti-saccade task. These results suggest that they find it difficult to voluntarily suppress reflexive saccades and initiate voluntary saccades when a target is invisible. In SPEM using step-ramp stimuli, the LD subjects showed lower open- and closed-loop gains. These results suggest disturbances of both acceleration of eye movement in the initial state and maintenance of velocity in minimizing retinal slip in the steady state. Recent anatomical studies in LD subjects have suggested abnormalities in the structure of certain brain areas such as the frontal cortex. Frontal eye movement-related areas such as the frontal eye fields and supplementary eye fields may be involved in these disturbances of voluntary control of eye movement in LDs.

Keywords: Learning disorders (LD); Anti-saccade task; Memory-guided saccade task; Smooth-pursuit eye movements; Latency; Open-loop gain; Closed-loop gain; Frontal eye fields

1. Introduction

Learning disorders (LDs) are defined as a developmental disorder in children and are characterized by learning difficulties at school. These difficulties do not occur as a result of low intelligence, lack of educational opportunity, visual, auditory or any other neurological disorder [1]. LDs include several specified disorders. According to the DSM-IV categorization, they are divided into the following four groups: reading disorder, mathematics disorder, disorder of written expression and learning disorder not otherwise specified.

* Corresponding author. Tel: +81 11 706 3329; fax: +81 11 706 4916.
E-mail address: jf002@cme.hokudai.ac.jp (J. Fukushima).

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Eye movement is important in allowing humans to acquire accurate vision. Saccadic eye movement is used to rapidly adjust the visual axis between the foveae and an object in order to aim, the foveae of both eyes at an object of interest (e.g. as in reading).

Many researchers have discussed the characteristics of eye movements during reading in dyslexia (reading disorder). Pavlidis [2] reported that the eye movements of dyslexics during reading were different from those of normal controls, suggesting that abnormal eye movements were responsible for the reading disability. However, other studies revealed no abnormalities in the eye movements of dyslexics during reading compared with those of control subjects [3,4]. It has been reported that there was no significant difference between dyslexia and normal controls in saccadic eye movements [5–7]. These reports suggest that abnormal eye movement during reading is not the cause of reading disability.

On the other hand, Biscardi et al. [8] reported that dyslexic patients showed a greater number of express saccades with latencies of 85–135 ms. They also reported that patients who showed higher rates of express saccades could not suppress reflexive saccades to the target in the memory-guided saccade task. This suggests that dyslexics may have difficulties in the voluntary control of saccadic eye movements, despite not showing any abnormalities in simple visually guided saccades. A previous study, we carried out on normal children also showed that maturation in executing complex saccade tasks (i.e. anti-saccades and memory-guided saccades) was delayed, compared with the results for a simple visually guided saccade task [9].

Children with LDs often have difficulties in more than two subcategories of DSM-IV, indicating that dyslexic children may also have other types of learning disabilities [10,11]. It has been reported that dyslexic subjects often showed sensorimotor abnormalities other than reading disabilities [12,13]. Moe-Nilssen reported that dyslexic subjects showed disturbances of balance and gait [13]. These studies suggest that the abnormal eye movements found in dyslexia may be a consequence of brain dysfunction or delayed development and not merely the cause of reading difficulties. It is possible that eye movement disorders may be characteristic of learning disorders in general. Therefore, we examined eye movement, not only in dyslexics but also in other LD subjects both with and without dyslexic symptoms. The primary aim of the present study was to compare performances in saccade tasks between LD subjects and age-matched normal children.

Another subsystem of eye movement is smooth-pursuit eye movement (SPEM), which is used to pursue a slowly moving small object [14]. Here, subjects must match the velocity of the eyes to the velocity of an object in order to keep the images of that object near the foveae in order to ensure online processing of visual signals during target movement. The major brain areas related to SPEM are the middle temporal (MT) and medial superior temporal (MST) visual areas. From there, descending fibers project directly to the dorsolateral pontine nucleus. There are also pathways through the frontal eye fields (FEF) and the supplementary eye fields (SEF) to the pontine nuclei. It has been reported that neurons in the FEF and SEF respond to SPEM [15–17]. Since the FEF and SEF are involved in both saccadic and smooth-pursuit eye movements, it is possible that LD subjects who show abnormalities in the control of saccadic eye movements may also show abnormalities in SPEM.

So far, little research has been done on SPEM in LD subjects. Ygge et al. [18] examined dyslexics using both sinusoidal and ramp-stimuli, and concluded that dyslexics showed no abnormalities. Black et al. [19] reported that there was no significant difference compared to controls, but that about 25% of dyslexics showed more intrusive saccades in response to a triangular wave stimulus. According to these studies, dyslexic subjects revealed no major abnormalities in SPEM. However, none of these studies examined initiation of pursuit. Also, it is necessary to further examine steady state SPEM quantitatively.

Because the latency of smooth-pursuit to a ramp target motion is 100–120 ms, the initial eye movement within 100–120 ms of onset of pursuit is driven entirely by visual inputs. During this open-loop condition [14], the eye accelerates to peak values with eye velocity usually overshooting target velocity, and sometimes showing oscillation after overshooting. However, with the later periods that allow visual feedback (i.e. closed loop condition), eye velocity is stable and almost identical to target velocity. A step-ramp stimulus [20] is commonly used to examine peak velocity in the open-loop condition and average velocity in the closed-loop condition. The second aim of this study, therefore, was to examine open and closed-loop responses in SPEM in LD subjects by using step-ramp target motion.

2. Methods

2.1. Subjects

This study has been approved by the ethics committee of Hokkaido University, School of Medicine. Informed consent was obtained from the subjects and their guardians following a full explanation of the procedures to be undertaken. LD subjects were recruited from an organization of parents of children with learning problems at school. All subjects fulfilled the criteria set out in the ‘Report by the Japanese Ministry of Science and Education’ (1999), which defines such subjects as those whose difficulties in learning at school are not the result of general low intelligence, poor educational opportunity or disabilities of hearing or visual acuity. We selected the subjects for this study in accordance with the diagnosis based on the DSM-IV categorization carried out by one of the authors, a child psychiatrist (S.T.). Table 1 summarizes the clinical characteristics of the LD subjects. The subjects used in the present study consisted of five children with reading disorder, two subjects with mathematics disorder, and 11 other subjects with learning disorders not otherwise specified. These 11 subjects had learning difficulties encompassing 2 or 3 subcategories. None of them had been diagnosed with Attention Deficit Hyperactivity Disorder (ADHD). The mean IQ of the LD subjects was 85 (verbal IQ 84, performance IQ 87) in WISC-R. Their visual acuity was normal or corrected to normal.

The subjects for the visually guided saccade task consisted of 18 children with LD (16 boys and two girls; mean ± SD: 11.4 ± 2.6) and 22 healthy children (21 boys and one girl; mean ± SD: 10.4 ± 2.5). None of the control children or their parents had any history of psychiatric, neurological, intellectual, or learning problems, and none had received medication. Eleven of the 22 control children participated in the SPEM task. The age of the control