Original article

Eye movements characteristics of Chinese dyslexic children in picture searching

HUANG Xu, JING Jin, ZOU Xiao-bing, WANG Meng-long, LI Xiu-hong and LIN Ai-hua

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Background Reading Chinese, a kind of ideogram, relies more on visual cognition. The visuospatial cognitive deficit of Chinese dyslexia is an interesting topic that has received much attention. The purpose of current research was to explore the visuopatial cognitive characteristics of Chinese dyslexic children by studying their eye movements via a picture searching test.

Methods According to the diagnostic criteria defined by ICD-10, twenty-eight dyslexic children (mean age (10.12±1.42) years) were enrolled from the Clinic of Children Behavioral Disorder in the third affiliated hospital of Sun Yat-sen University. And 28 normally reading children (mean age (10.06±1.29) years), 1:1 matched by age, sex, grade and family condition were chosen from an elementary school in Guangzhou as a control group. Four groups of pictures (cock, accident, canyon, meditate) from Picture Vocabulary Test were chosen as eye movement experiment targets. All the subjects carried out the picture searching task and their eye movement data were recorded by an Eyelink II High-Speed Eye Tracker. The duration time, average fixation duration, average saccade amplitude, fixation counts and saccade counts were compared between the two groups of children.

Results The dyslexic children had longer total fixation duration and average fixation duration (F=7.711, P <0.01; F=4.520, P <0.05), more fixation counts and saccade counts (F=7.498, P <0.01; F=11.040, P <0.01), and a smaller average saccade amplitude (F=29.743, P <0.01) compared with controls. But their performance in the picture vocabulary test was the same as those of the control group. The eye movement indexes were affected by the difficulty of the pictures and words, all eye movement indexes, except saccade amplitude, had a significant difference within groups (P <0.05).

Conclusions Chinese dyslexic children have abnormal eye movements in picture searching, applying slow fixations, more fixations and small and frequent saccades. Their abnormal eye movement mode reflects the poor ability and strategy of visual information processing.

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Developmental dyslexia is one of the specific academic skills developmental disorders, which is defined as a marked impairment in the development of reading skills despite adequate intelligence, good vision and adequate instruction.[1] The prevalence rate of dyslexia in school age children is approximately 5%–10%.[2,3] It can cause negative effects on children's cognition, emotion, self-awareness and social development. Understanding the cognitive characteristics and mechanism of dyslexia is the basis of intervention.

Many studies on dyslexia of alphabetic writing systems have shown that its core deficit is phonological awareness disorders. However, Chinese characters are ideographic script whose grapheme combined with pronunciation and morphemes. The visual structure of Chinese characters is quite different from alphabetic script, and its visual processing depends more on visuospatial cognition.[4] Recently, the view of visuospatial cognitive deficit of Chinese dyslexia received much attention.

Eye movement experiments can reflect the visual processing and information integration through exploring the fixation sequences and saccades of the eyeball, and infer the perception process of reading. Eye movement track recording is a kind of natural experiment with few disturbances, known as one of the effective methods in visual information processing research. Studies have shown that the eye movements of dyslexia are different from that of normal readers, and there may be a relation between abnormal eye movements and dyslexia.[4] However, studies about the eye movement characteristics of Chinese dyslexia are few.[5] This study examined the eye movements of Chinese dyslexia, to explore their visuopatial cognitive characteristics.

Faculty of Maternal and Child Health, Preventive Medicine Institute, School of Public Health, Sun Yat-sen University, Guangzhou, Guangdong 510080, China (Huang X, Jing J, Wang ML and Li XH)
Child Developmental and Behavioral Center, Third Affiliated Hospital of Sun Yat-sen University, Guangzhou, Guangdong 510630, China (Zou XB)
Faculty of Epidemiology and Health Statistics, School of Public Health, Sun Yat-sen University, Guangzhou, Guangdong 510080, China (Lin AH)
Correspondence to: Dr. JING Jin, Faculty of Maternal and Child Health, School of Public Health, Sun Yat-sen University, Guangzhou 510080, China (Tel: 86-20-87333526. Fax: 86-20-87330446. Email: jingjin@mail.sysu.edu.cn)
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METHODS

Experimental groups

All the dyslexic children in this study were referred from the Clinic of Children Developmental Behavioral Disorder in Third Affiliated Hospital of Sun Yat-sen University. According to the diagnostic criteria defined by ICD-10, 28 children with dyslexia are diagnosed through reviewing their clinical history, clinic observation, schoolwork investigation and the academic evaluation by teachers and parents. The children were in 3 to 6 grade from primary school, and their mean age was 10.12 ±1.42 years. Twenty-two of them were boys and six were girls. Inclusive criteria were: (1) sufficient school education, but poor learning abilities (Chinese performance below 5% in the class); (2) reading skills lagged according to teachers and parents questionnaire;[6] (3) the total score of pupil rating scale revised screening for learning disabilities (PRS)[7] was lower than 60 points; (4) the intelligence quotient was above 70 assessed by Wechster intelligence scale for children; (5) excluded attention deficit/hyperactivity disorders, mental retardation, pervasive developmental disorder, emotion disorder and visual and auditory disorders.

Matched in age, sex, grade, family economic status, parents' literacy and occupation, 28 children with normal reading skills were enrolled from a primary school in Guangzhou as control group. The control group children were in 3 to 6 grade from primary school, and their mean age was 10.06±1.29 years.

Informed consents were obtained from all the participants and their parents or guardians according to the medical ethics principles before experiments. All the participants were rewarded a gift after the test.

Experimental instrument and material

An Eyelink II High-Speed Eye Tracker was used to record the eye movements of subjects. Eyelink II has a fast data rate (500 samples per second) and high resolution (spatial resolution <0.005°, noise-limited at <0.01°). The mean error of fixation position is less than 0.5°. The target presenting screen is a 21 inch screen.

The eye movement targets were 4 groups of pictures chosen from the Peabody Picture vocabulary test (PPVT). Each group of picture included 4 black and white pictures among which one represents an objective word. The objective words of the 4 groups of pictures were cock, accident, canyon and meditate. The picture were presented full screen and the subjects were asked to indicate the picture representing the object word.

Experimental procedure

The subject sat on a chair, 70 cm from the computer screen. The illumination of the monitor is 200 lux. The experimenter set and calibrated the system at first, then explained the instruction to the subjects. When the subjects were sure that he/she understood the experiment requirement, the experiment could begin. After the experimenter reading an objective word, the pictures were presented and the eye movement data were recorded at the same time. As soon as the subject made a react, the target disappeared. The experimenter recorded the answers of the subjects, noting 1 for correct answer and 0 for wrong answer.

Statistical analysis

The eye movement data were recorded and exported by the Eyelink Data Viewer. Eye movement indexes included total fixation duration, average fixation duration, fixation count, saccade count and average saccade amplitude.

All statistical tests were expressed as mean±standard deviation (SD), and performed by SPSS (v 12.0) software on a personal computer. The eye movement indexes of two groups of children were analyzed with a paired *t*-test and repeated measures variance analysis. A P <0.05 was considered statistical significantly.

RESULTS

Total duration

By repeated measures variance analysis, it was found that there was a significant difference in total fixation duration between dyslexics and controls (F=7.711, P=0.008), and among different groups of pictures (F=22.236, P=0.000). There was no interaction between materials and groups (F=0.797, P=0.482). We used a paired *t*-test to compare the total fixation duration between two groups in each trial. The findings (Table 1) showed that dyslexic children had longer total fixation duration than control group children during searching for cock, accident and meditate while no difference existed in searching for canyon.

Average fixation duration

According to repeated measures variance analysis, there was a significant difference in average fixation duration between the two groups (F=4.520, P=0.038) and among different groups of pictures (F=25.261, P=0.000), and there was interaction between materials and groups (F=2.875, P=0.038). We used paired *t*-tests to compare the average fixation duration between two groups in each trial. The results (Table 2) showed that dyslexic children had longer average fixation duration than control group during their searching for cock, accident and meditate while no difference in searching for canyon.

Fixation counts

According to repeated measures variance analysis, there was a significant difference in fixation counts between two groups (F=7.498, P=0.008) and among different groups of pictures (F=19.680, P=0.000), and there was no interaction between materials and groups (F=0.442, P=0.690). We used a paired *t*-test to compare the fixation

Table 1. The total fixation duration of two groups of children in PPVT (mean±SD, *n*=28)

Groups	Cock (ms)	Accident (ms)	Canyon (ms)	Meditate (ms)
Dyslexia	35367.29±2669.05	5163.29±1964.17	7441.43±4444.57	5233.57±4266.15
Controls	2222.00±1053.93	2716.14±1022.52	6484.14±3545.46	3290.43±1269.23
t value	2.833	2.612	0.995	2.336
P value	0.009	0.015	0.328	0.027

Table 2. The average fixation duration of two groups of children in PPVT (mean±SD, *n*=28)

Groups	Cock (ms)	Accident (ms)	Canyon (ms)	Meditate (ms)
Dyslexia	220.22±40.60	241.49±46.75	252.33±35.50	236.99±30.35
Controls	198.14±30.96	217.99±34.26	254.10±36.06	214.41±42.04
t value	2.324	2.739	-0.284	2.534
P value	0.028	0.011	0.779	0.017

counts between the two groups in each trial. The results (Table 3) showed that dyslexic children had more fixation counts than the control group during their searching for cock and accident while no difference in searching for canyon and meditate.

Table 3. The fixation counts of two groups of children in PPVT (mean±SD, *n*=28)

Groups	Cock	Accident	Canyon	Meditate
Dyslexia	16.21±11.31	20.39±15.92	28.93±16.01	21.36±14.81
Controls	11.07±4.28	12.36±3.70	25.00±11.61	15.54±5.64
t value	2.617	2.677	1.139	1.963
P value	0.014	0.012	0.265	0.060

Saccade counts

According to repeated measures variance analysis, there was a significant difference in saccade counts between two groups (F=11.040, P=0.002) and among different groups of pictures (F=22.829, P=0.000), and there was no interaction between materials and groups (F=0.427, P=0.706). We used a paired *t*-test to compare the saccade counts between two groups in each trial. The results (Table 4) showed that dyslexic children had more saccade counts than the control group during searching for cock, accident and meditate with no difference in searching for canyon.

Table 4. The saccade counts of two groups of children in PPVT (mean±SD, *n*=28)

Groups	Cock	Accident	Canyon	Meditate
Dyslexia	16.04±11.48	20.86±15.92	30.96±16.11	23.75±14.64
Controls	10.82±4.22	11.96±3.52	24.96±12.06	15.71±6.84
t value	2.591	2.978	1.647	2.578
P value	0.015	0.006	0.111	0.016

Saccade amplitude

According to repeated measures variance analysis, there was a significant difference in saccade amplitude between the groups (F=29.743, P=0.000), but the difference among different groups of pictures was not significant (F=2.006, P=0.123), and there was no interaction between materials and groups (F=1.316, P=0.272). We used a paired *t*-test to compare the saccade amplitude between two groups in each trial. The results (Table 5) showed that dyslexic children had a smaller saccade amplitude than the control group during searching for cock, accident, canyon and meditate.

Table 5. The saccade amplitude of two groups of children in PPVT (mean±SD, *n*=28)

Groups	Cock (degree)	Accident (degree)	Canyon (degree)	Meditate (degree)
Dyslexia	6.10±1.09	5.96±1.49	5.59±1.08	5.23±1.03
Controls	7.22±1.63	7.22±1.57	6.98±1.34	7.17±1.88
t value	–2.665	–2.700	–4.615	–5.982
P value	0.013	0.012	0.000	0.000

Performance on PPVT

According to repeated measures variance analysis, the score of PPVT among searching for different pictures was significantly different (F=46.230, P=0.000), the score of searching for "canyon" was significantly lower than the other three tasks. No significant difference was found between two groups of children (F=3.931, P=0.052), and no interaction was found between materials and groups (F=1.035, P=0.360). We used a paired *t*-test to compare the score on PPVT between the two groups in each trial and found no significant difference between the two groups of children.

DISCUSSION

A number of studies have shown that eye movements are abnormal in dyslexics reading an alphabetic script. When reading words, the ability of adjust saccade amplitude according to the length of words is impaired in dyslexia,[8] the saccade counts increase as the word length increases while the saccade amplitude stays small with regression increasing.[9] When reading text, dyslexics have a longer fixation count, longer fixation duration, more frequent saccade and a smaller saccade amplitude than that of normal reader.[10,11] Domestic studies have found that Chinese children with learning disabilities also have abnormal eye movements, such as more fixation counts, narrower fixation range, longer fixation duration, smaller saccade amplitude and more regression.[12,13]

There is significant difference between picture and reading processing. Picture is an ideographic symbol system, which can approach the meaning directly. The perception of pictures mainly depends on the visual strategy while the word identification in reading needs language coding.[14] Furthermore, picture searching also involves visual attention, especially the selective attention. Therefore, the abnormal eye movement in PPVT may reflect the visual processing strategy deficit and visual attention deficit.

Eye movement model and cognitive processing deficit of dyslexic children on PPVT

Total fixation duration reflects cognitive processing speed and access to the meaning of pictures. Average fixation duration reflects the picture processing level and speed of

the subject. The longer fixation duration, the deeper the processing for a same subject; and the longer fixation duration, the slower the processing speed is for different subjects. In the current study, dyslexic children had longer total fixation duration and average fixation duration, indicating their slow cognitive processing and poor picture information acquiring ability. Dyslexics need a longer time to extract enough information to understand the pictures, while the control group children can quickly get useful information from picture by quick fixation and understand it. It has been proven that visual scanning abilities in kindergarten is a good predictor of reading acquisition.[15] Dyslexic children's poor reading ability might relate with their slow scanning in visual searching.

Fixation counts indicate the reading dexterity, strategy and the difficulty of reading material. The current study show redundant fixation in dyslexic children demonstrating their poor searching strategy. They shift fixation point back and forth among four pictures and cannot find the target picture until repeated fixations. Redundant fixation also suggests dyslexic children have difficult in distinguishing target pictures from other pictures, can not quickly exclude other pictures by detecting the difference of single characteristic, thus induce repeated fixation to compare each picture one by one and make a judgment. It is believed that during looking at picture the subjects need to constantly jump between different nodes, so they have to keep the relation between each information node when searching, causing a cognitive load increase.[16] This level of cognitive load is not difficult for normal children, but is rather difficult for dyslexic children, thus causing frequent fixation.

The study also showed that dyslexic children had excessive saccade in searching for the four target pictures. Because the visual acuity decreases significantly during saccade, excessive saccade of dyslexic children interferes with acquiring information, consequently causing processing slowing and impeding acquiring the meaning of pictures.

Saccade amplitude is an important index reflecting the span of perception and attention range. The larger the saccade amplitude is, the larger the span of perception is, and the more information a subject can acquire in one fixation, so the reading efficiency is higher.[17] Prado et al[18] believes that the poor visual attention span abilities of dyslexic children might contribute to their atypical eye movement patterns. Dyslexic children have difficulties in increasing their visual attention span according to the task request, causing the number of rightward fixations to increase during text reading. The current study finds the saccade amplitude of dyslexia is smaller than that of the control group, demonstrating that their visual attention span is narrow. Therefore, they cannot observe more information and shift attention among different pictures to find target at the same time, and can only execute the picture searching task through repeated fixation. Small saccade amplitude of dyslexic children means they use a poor searching strategy of partial processing model –divide the picture into small units–and the integrative level of picture information is low. Cognitive experiments shows that the subject's spatial resolution is strong and suitable to partial processing when attention is focused in a small range, and decreased and is suitable to undertake integral processing when the attention is expanded to a wide range.[19] The frequent and small saccade found in dyslexic children in current study suggests that their attention span is limited and processing is too deep in a local area. They are not good at utilizing background information to integrate the meaning of materials, so they prolong the time of integrating the material, and this influences the speed of picture searching.

Performance in PPVT

PPVT is a screening test to evaluate children's general intelligence. It mainly tests the word hearing understanding and association ability. Executing the test requires the ability to hear words with understanding and the visual identification of pictures and also requires visual attention, especially selective attention. The current study shows that the performance of dyslexic children had no significant difference compared with the control group, but their searching time is longer than that of controls. The findings show that dyslexic children can understand the word presented by the auditory pathway and acquire meaning from the pictures and find the pictures representing the target words. However, their visual processing is too slow, so only through slow processing could they acquire useful information and find the target pictures.

Effect of picture variable on eye movement indexes

We find that the total fixation duration, average fixation duration, fixation count, saccade count and performance in PPVT are significantly affected by material variables. The findings show that the content characteristics of pictures and the difficulty of words influence the eye movement indexes and behavioral response performance of PPVT. Among the four target words, "cock" is a concrete noun, and the picture it corresponds to is simple with obvious subjects, easy to search for. "Accident" is an abstract noun corresponding to simple pictures, and is easy to identify. "Canyon" is unfamiliar to children, and the picture it corresponds to is complex and unclear and hard to discern. "Meditation" is a verb, the picture it corresponding to is relatively complicated but its background is not as obscure as "canyon". Therefore, "canyon" is the most difficult among the four trials. *T*-test between two groups shows that all eye movement indexes except saccade amplitude had no significant difference between the two groups when searching for canyon. While searching for pictures corresponding to the other three words, the eye movement indexes have a significant difference between the two groups, and the difference trend was consistent. Researchers consider that the difficulty of visual processing depends on the difficulty of the materials. When the materials have moderate

difficulty, eye movement diversities between dyslexic children and normal children can be discovered. When the materials become difficult (for example, canyon), normal children also have to prolong fixation time and increase fixation counts to ensure the quality of visual processing, so there is no significant difference in eye movement index between dyslexic and normal children. Saccade amplitude is not affected by the difficulty of the material, suggesting that individual's span of visual perception may be relatively steady.

In summary, Chinese dyslexic children have an abnormal eye movement model-slow fixation, redundant fixation, small step and frequent saccade–which demonstrate their poor abilities and strategies at visual processing.

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