Original article

Picture perception in Chinese dyslexic children: an eye-movement study

LI Xiu-hong, JING Jin, ZOU Xiao-bing, HUANG Xu, JIN Yu, WANG Qing-xiong, CHEN Xue-bin, YANG Bin-rang and YANG Si-yuan

Keywords: *children; dyslexia; eye movement; picture*

Background Currently, whether or not there is visuospatial impairments in Chinese dyslexic children is still a matter of discussion. The relatively recent application of an eye-tracking paradigm may offer an opportunity to address this issue. In China, in comparison with reading studies, there have not been nearly as many eye movement studies dealing with nonreading tasks such as picture identification and whether Chinese children with dyslexia have a picture processing deficit is not clear. The purposes of the present study were to determine whether or not there is visuospatial impairments in Chinese dyslexic children. Moreover, we attempted to discuss whether or not the abnormal eye movement pattern that dyslexic subjects show during reading of text appropriate for their age is a consequence of their linguistic difficulties.

Methods An eye-link II High-Speed Eye Tracker was used to track the series of eye-movement of 19 Chinese dyslexic children and 19 Chinese normal children. All of the subjects were presented with three pictures for this eye-tracking task and 6 relative eye-movement parameters, first fixation duration, average fixation duration, average saccade amplitude, mean saccade distance, fixation frequency and saccade frequency were recorded for analysis.

Results Analyzing the relative parameter among three pictures, except for the fixation frequency and the saccade frequency, other eye-movement parameters were significantly different among the three pictures (P <0.05). Among the three pictures, the first fixation duration was longer, and the average fixation duration, the average saccade amplitude and the mean saccade distance were shorter from picture 2 to picture 3. Comparing all eye-movement parameter between the two groups, the scores of average saccade amplitude (P=0.017) and the mean saccade distance (P=0.02) were less in the dyslexia group than in the normal group (P <0.05), other parameters were the same in the two different groups (P >0.05).

Conclusions The characteristics of the pictures can significantly influence the visuospatial cognitive processing capability of the Chinese children. There is a detectable disability for the Chinese dyslexic children in the visuospatial cognitive processing: their saccade amplitude and mean saccade distance are shorter, which may be interpreted as specific for their reading disability.

Chin Med J 2009;122(3):267-271

Dyslexia is one of the most common clinical groups of learning disabilities. According to International Classification of Disease (ICD)-10,[1] dyslexia is defined as the "Development of special reading ability is damaged seriously despite conventional instruction, adequate intelligence and the absence of gross neurological pathology. This problem will impact the ability of reading comprehension, words recognition, reciting and other works related to reading." In alphabetic scripts countries about 5.0%–17.5% of the population suffer from dyslexia, affecting 80% of all those identified as learning-disabled.[2] In Chinese school-aged children, the rate of dyslexia is about 4%–8%.[3] Dyslexia not only affects the cognition of the afflicted child, but also has an effect over other corresponding developmental milestones such as sensibility, self-conception and social development.[4]

While the claim that most dyslexics show that phonological dysfunctions as well as poor performance in many linguistic tasks are well accepted in western countries,[4] the presence of visual impairments is relatively under-studied.[5] The role of visual processing in reading is especially important in nonalphabet countries, such as China. As a kind of idiograph, Chinese has figure characteristics which are different from alphabets such as English. Some experts indicate that cognitive processing in Chinese demands stronger visual special processing capabilities and visuospatial capacity is more important in

DOI:10.3760/cma.j.issn.0366-6999.2009.03.006

Faculty of Maternal and Child Health, Preventive Medicine Institute, Department of Public Health, Sun Yat-sen University, Guangzhou, Guangdong 510080，China (Li XH, Jing J, Huang X, Jin Y, Wang QX, Chen XB, Yang BR and Yang SY)

Children Development and Behavior Center, Third Affiliated Hospital of Sun Yat-sen University, Guangzhou, Guangdong 510630, China (Zou XB)

Correspondence to: Prof. JING Jin, Faculty of Maternal and Child Health, Preventive Medicine Institute, Department of Public Health, Sun Yat-sen University, Guangzhou, Guangdong 510080, China (Tel: 86-20-87333526. Fax: 86-20-87330446. Email: Jingjin@mail. sysu.edu.cn)

This study was supported by the grants from the National Natural Science Foundation of China (No. 30671771, No. 30600207) and Medicine Research Foundation of Guangdong Province (No. A2006168).

Chinese reading.[6,7] However, Ho et al[8] reported that Chinese dyslexia is a phonologic disability, not a visual skill disorder. Currently, whether or not there are visuospatial impairments in Chinese dyslexia is still a matter of discussion. The relatively recent application of an eye-tracking paradigm may offer one opportunity to address such an issue.[9]

A study has used eye movements to investigate cognitive processes over the past 30 years.[10] Eye movement data have proven to be very informative for revealing on-line visuospatial processing activities in tasks such as reading, music reading, typing, visual search and scene perception.[6] When we read, look at a scene, or search for an object, we continually make eye movements called saccades. We make saccades so frequently because of acuity limitations. As we look straight ahead, the visual field can be divided into three regions: foveal, parafoveal and peripheral. Although acuity is very good in the fovea (the central 2° of vision), it is not nearly so good in the parafovea (which extends out to 5° on either side of fixation) and it is even poorer in the periphery (the region beyond the parafovea). Hence we move our eyes so as to place the fovea on that part of the stimulus we want to see clearly.[10] When we identify images, we change fixation situation through fast saccade and collect information through fixation pause, the changes of fixation situations and the duration of fixation pause are decided by the central nervous system which control the extraocular muscles to collect, recognize and deal with information in the best way. Hence the eye-movement records can reflect the space and time order relation of information processing during image identification, and to analyse the saccade rules help us to reveal the mechanism of visual image identification.[9]

As yet, most eye-movement studies are about reading. Those studies showed that dyslexic readers make longer fixations, shorter saccades, more fixations and more regressions than normal readers.[11] But the critical issue is whether or not reading disability in the absence of obvious oculomotor problems can be attributed to faulty eye movement. If eye movement is a causative factor in reading disability, then the problems can be easily diagnosed with a simple eye movement test and oculomotor training will result in improved reading. Although there have been some demonstrations that oculomotor training improves reading performance, some researchers argued quite strongly that eye movements are generally not a cause of reading disability but a reflection of other underlying problems.[10] Recent work has shown that normal reading subjects, as well as dyslexics, make a higher number of saccades and, in particular, of regressions and longer fixation durations when they read text material with difficulty above their present achievement level.[12] Currently it is still a debated question as to whether the abnormal eye movement pattern that dyslexic children show during reading of text appropriate for their age is specific for their reading disability or rather is a consequence of their linguistic difficulties.

Picture processing is a nonreading task. According to the dual coding theory,[8] the cognitive system consists of verbal and visual systems, both of which are responsible for linguistic input and output. The verbal system specializes in processing and storing linguistic information. In contrast, the visual system specializes for the representation and processing of nonverbal objects. Trauzettel-Klosinski et al[13] suggested that the visual system could process pictures independently, and picture perception mainly made use of visual strategy and did not involve the verbal system. Therefore, considering saccadic eye movement made in picture perception can help resolve the above two controversies. But in China, in comparison with reading, there have not been nearly as many eye movement studies dealing with nonreading tasks such as picture identification and whether dyslexic children have a picture processing deficit is not clear.

The purposes of the study were to study whether or not there are visuospatial impairments in Chinese dyslexic children. Moreover, we attempted to discuss whether or not the abnormal eye movement pattern that dyslexic children show during reading of text appropriate for their age is a consequence of their linguistic difficulties.

METHODS

Dyslexia group

Nineteen primary school children (17 boys and 2 girls) from grades 2 to 6, mean age (9.54±1.41) years old, were recruited from the Children Development and Behavior Center in Guangzhou, China. They all met the diagnostic criteria according to the DSM-IV (American Psychiatric Association, 1994) and ICD-10.[1] Additional criteria for being recruited for the present study included: (1) normal learning experience but poor school performance as indicated in their position in the lower 5% or failure to go up to the next grade; (2) abnormal manifestations in reading and writing such as slower reading speed, reading one by one, misreading tune, misidentifying similarity front style, missing words, missing a line of an article, impairment in their ability to write or more wrongly written or mispronounced characters as reported by parents and school teachers; (3) IQ ≥70. Potential subjects were excluded if they demonstrated disability in vision and hearing, emotion disorders or attention deficit hyperactivity disorder (Table).

Normal group

Nineteen school-aged children with normal reading ability were also recruited as controls. All of them were screened by the Pupil Rating Scale (PRS) Revised, Conners Children Behavior Scale for Teachers and Parents, the Wechsler Young Children Scales of

Intelligence (C-WISC) and a children′s reading and writing ability questionnaire for parents[14] in order to ascertain the healthy controls did not suffer from any emotion disorder, attention deficit hyperactivity disorder, learning disorder or other neuropsychological diseases. No significant differences were found between the two groups in age, gender, school grade, parent education and occupational status, and family financial situations. This study was approved by the Ethics Committee of the Hospital and the Sun Yat-sen University. Written consent forms were obtained from the parents of the children with dyslexia and healthy controls.

Apparatus

Eye movements were recorded by an Eye-link II High-speed Eye Tracker produced by the Canadian company, SR Research Ltd. Each subject viewed the target pictures on a 48.26 cm (19-inch) Dell Trinitron monitor connected to a personal computer (PC). Subjects wore a light-weight helmet that is part of the eye-tracking system. The eye tracking system samples at a rate of 250 Hz and provides eye movement data for data analysis via another PC. Although the Eyelink II system compensates for head movements, subjects rested their heads in a chin rest to minimize head movements during the experimental trial. Subjects were seated 75 cm from the video monitor. When the experiment began, mean illumination degree on the screen was 200.00l×. Exercise was required for 2–5 minutes before the test. The test started after the subjects understand the demands of the experiment. The relative eye-movement parameters included: (1) first fixation duration (FFD): the duration (in milliseconds) of the first fixation on a picture, (2) average fixation duration (AFD): average duration (in milliseconds) of all fixations in the trial, (3) fixation frequency (FF): total number of fixations in the trial recording every millisecond, (4) average saccade amplitude (ASA): average size (in degrees of visual angle) of the saccades in the trial, (5) mean saccade distance (MSD): measures the distance (in degrees of visual angle) between contiguous fixations, (6) saccade frequency (SF): total number of saccades in the trial recording every millisecond.

Target design

We chose three pictures as eye-movement experiment targets. These pictures were selected according to whether or not the theme is outstanding. For example, picture 1 is composed of an object occupying about half of the background in order to ascertain a clear portrayal of the object. In picture 2, the size of the object is reduced to about 1/3 the whole layout of the picture. In picture 3, the size of the object is about 1/6 of the picture layout. Each subject was told that there would be a picture appearing for 60 seconds in the computer screen and they were requested to attend to every feature of the object in the picture. After the picture disappeared from the computer screen, the subject was requested to answer the questions specifically captured in the details of each object in the pictures (Figure).

Statistical analysis

All data were expressed as mean ± standard deviation (SD). The eye-movement experimentation results were extracted with Eye-movement Analysis Software of the Eye Tracker. The data were processed and analyzed with SPSS 11.0. The general linear model (GLM) repeated measure was used to test results between groups (dyslexic vs normal), among pictures (picture 1 vs picture 2 vs picture 3) and the interaction effects. P values less than 0.05 were considered statistically significant.

RESULTS

FFD

The results of GLM repeated measure indicated that subjects had a significantly longer FFD from picture 3 to picture 2 (F=25.10, P <0.001). However, there were no significant differences in FFD between dyslexic group and normal group (F=0.64, P=0.43) nor interaction effects between pictures and groups (F=0.21, P=0.75).

AFD

There was a significant difference in AFD (F=3.46, P=0.039) among the three pictures and the AFD in picture 1 was the longest, and picture 2 was the shortest. No significant differences were found in AFD between dyslexic group and normal group (F=1.22, P=0.28) nor interaction effects between pictures and groups (F=0.16, P=0.84).

FF

Results of GLM repeated measure indicated that no significant differences were found in FF among the three pictures (F=1.99, P=0.16), between dyslexic group and normal group (F=0.08, P=0.78) and interaction effects between pictures and groups (F=0.03, P=0.92).

ASA

Results of GLM repeated measure indicated that subjects had a significantly longer ASA from picture 3 to picture 2 (F=6.17, P=0.006). At the same time, dyslexic group had a significantly shorter ASA than the normal group (F=6.27, P=0.017). There was no significant difference in ASA for interaction effects between pictures and groups (F=1.60, P=0.21).

MSD

Results of GLM repeated measure indicated that subjects had a significantly longer MSD from picture 3 to picture 2 (F=11.21, P <0.001). At the same time, dyslexic group had significantly shorter MSD than the normal group (F=5.62, P=0.02). There was no interaction between pictures and groups (F=0.004, P=0.99).

SF

Results of GLM repeated measure revealed that there

Figure. The pictures selected for eye-movement experiment targets in the target design.

Table. Main eye-movement parameters on the target pictures (mean±SD)

Eye-movement parameters	Picture 1		Picture 2		Picture 3	
	Dyslexic	Normal	Dyslexic	Normal	Dyslexic	Normal
FFD (ms)	338.11±88.38	363.37±40.65	466.11±152.56	466.74±147.91	303.79±76.06	329.68±58.99
AFD (ms)	337.31±87.81	317.26±74.04	311.84±69.06	294.72±44.32	337.08±68.22	309.25±68.34
FF (ms)	2.26±0.77	2.36±1.52	2.56±0.66	2.69±1.49	2.33±0.66	2.37±1.54
ASA (degrees)	4.17±1.06	4.62±0.94	3.61±0.94	4.19±0.69	3.90±0.81	4.91±1.50
MSD (degrees)	3.92±0.71	4.44±0.75	3.66±0.72	4.16±0.63	4.22±4.73	1.04±0.83
SF	2.82±0.67	2.89±1.46	3.06±0.53	3.17±1.49	2.65±0.82	2.93±1.79

were no significant differences in SF among the three pictures (F=1.49, P=0.23), between dyslexic group and normal group (F=0.22, P=0.64) or interaction effects between pictures and groups (F=0.16, P=0.75). Mean and SD of all eye-movement parameters are shown in Table.

DISCUSSION

Effect of the picture characteristics on the children's visual online processing

It has been advocated that the gist of the scene is abstracted on the first couple of fixations, and the remainder of the fixations on the scene are used to fill in details.[10] The results of our study showed that there were significant differences in first fixation duration, average fixation duration, average saccade amplitude and mean saccade distance, but not in fixation frequency and saccade frequency, among the three pictures. Among the three pictures, picture 2 had the longest first fixation duration, and the shortest average fixation duration, average saccade amplitude and mean saccade distance, while picture 3 was the opposite. The results suggested that the visual on-line processing for picture 2 was the most complicated, while picture 3 was the opposite. Researchers thought that picture 2 had the most meaning details, which made it form more perception integrations, while details in picture 3 were the fewest, and picture 1 had an intermediate number of details. The above mentioned demonstrates that the picture characteristics can significantly affect children's visual online processing characteristics during picture perception: the more meaningful details in pictures, the more complicated the visual processing is. At the same time, the results also demonstrated that these eye-movement parameters, such as first fixation duration, average fixation duration, average saccade amplitude, and mean saccade distance, can reflect online processing of the picture, but the two parameters of fixation frequency and saccade frequency are not sensitive enough to reflect online processing of the picture.

Comparison of eye-movement parameters between dyslexia group and normal group

This research found that the dyslexic children had a significantly shorter average saccade amplitude and mean saccade distance than the normal children, and this was not under the influence of the picture's characteristics.

Average saccade amplitude is of average size (in degrees of visual angle) of the saccades in the test. The mean saccade distance measures the distance between contiguous fixation (in degrees of visual angle), which is one important index of perceptual span. Perceptual span is termed the number of characters that a reader processes, at least partially, during a fixation.[15] The longer the saccadic distance, the more information is obtained in one fixation. Chinese dyslexic children employ short amplitude saccades and short distance fixations, therefore they get less information than normal children in one fixation, which show that their efficiency of fixation is low.

While the coarse space information of the stimulus can be available during a saccade, the stimulus evokes very little response from the visual cortex. Therefore, saccades can be used to scan the visual field and select the stimulus.[9] Generally, to adapt the environment, we need to select the relevant information in the visual field, while neglecting irrelevant information in order to effectively reduce the workload and duration of processing retinal images.[9] Related cognitive trails indicated that people can focus their attention on a narrow area and also extend it over a wider area. When focusing attention on a narrow area, people will have higher space identification, which is suitable for local processing. When focusing attention on wider area, people will be fit for global processing because their space identification is reduced.[16] In this test, data and eye movement track all indicated that dyslexic children employ small amplitude saccades and small distance fixation during picture perception. The results showed that dyslexic children adopt a local processing model and not a global processing model which is propitious for integration of information.[9] Thus it can be seen that the disordered eye movement model of dyslexia not only affects visual search speed and the choice of the effective information but also impacts integration of information, which lead to their low efficiency of fixation.

To summarize, the findings showed that these Chinese dyslexic children had abnormal eye movement patterns during nonreading tasks such as picture processing, which showed that Chinese dyslexia had a visuospatial deficit. It did not lead to visual difficulty but affect their ability to gain, process and integrate visual information during reading.[12] However, the results do not concur with other studies in western countries which have failed to find differences between normal and dyslexic readers′ eye movements during nonreading tasks.[10] This may mean that there are differences in the cognitive disability model between Chinese-spoken dyslexic and dyslexic readers in alphabet countries; a visuospatial deficit is an important cause of reading problems for Chinese dyslexic readers but not for dyslexic readers in alphabet countries. Finishing a series of cognitive processes during reading requires a complicated and integrated neural system which establishes contact with the visual centre, language centre and memory centre. Any problems in these neural centers can lead to dyslexia. In alphabet countries, phonologic capacity is the most important factor to affect reading. As a result, phonological dysfunctions became the core of dyslexic problems.[2-5] However, different from an alphabet, such as English, as a kind of idiograph, Chinese has figure characteristics, so visuospatial capacity is basic to learn Chinese characters, which is the foundation of Chinese reading.[17] Some experts indicated that cognitive processing of Chinese demands stronger visual special processing capabilities, that visuospatial capacity is more important in Chinese reading, and that a visuospatial deficit was the core problem of Chinese dyslexia children.[6,7,17] Our study supported that a visuospatial deficit was one of reasons causing reading problem for Chinese dyslexic readers, but whether or not it was the core problem needs study further. In addition, according to the conclusion that Chinese dyslexic children had abnormal eye movement patterns during nonreading tasks, the authors thought that the abnormal eye movement patterns that Chinese dyslexic children showed during reading of text appropriate for their age can not be simply seen as a consequence of their linguistic difficulties but as a reason for it. Finally, because there was a small sample number in this study, the conclusions above need to be tested in further studies with an increased sample number.

Acknowledgements: We are grateful to the children and their teachers who participated in this research.

REFERENCES

1. World Health Organization. ICD-10 classification of mental and behave disorders. 10th ed. Beijing: People′s Medical Publishing House; 1993: 192-193.
2. Sally E, Shaywitz MD. Dyslexia. N Engl J Med 1998; 338: 307-312.
3. Stevenson HW, Stigler JW, Lucker GW, Lee S, Hsu C, Kitamura S. Reading disabilities: the case of Chinese, Japanese and English. Child Dev 1982; 53: 1164-1181.
4. Demonet JF, Taylor MJ, Chaix Y. Developmental dyslexia. Lancet 2004; 363: 1451-1460.
5. Evans BJ, Drasdo N. Review of ophthalmic factors in dyslexia. Ophthal Physiol Opt 1990; 10: 123-132.
6. Eden GF, Zeffiro TA. Neural systems affected in developmental dyslexia revealed by functional neuroimaging. Neuron 1998; 21: 279-282.
7. Peng DL. Cognitive processing of the Chinese language and its neural mechanism. Contemp Linguistics (Chin) 2004; 6: 302-320.
8. Ho CS, Chan DW, Lee SH, Tsang SM, Luan VH. The cognitive profile and preliminary subtyping in Chinese developmental dyslexia. Cognition 2004; 91: 43-75.
9. Prado C, Dubois M, Valdois S. The eye movements of dyslexia children during reading and visual search: impact of the visual attention span. Vision Res 2007; 47: 2521-2530.
10. Rayner K. Eye movements in reading and information processing: 20 years of research. Psychol Bull 1998; 124: 372-422.
11. De Luca M, Borrelli M, Judica A, Spinelli D, Zoccolotti P. Reading words and pseudowords: an eye movements study of developmental dyslexia. Brain Lang 2002; 80: 617-626.
12. Reichle ED, Pollatsek A, Fisher DL, Rayner K. Toward a model of eye-movements control in reading. Psychol Rev 1998; 105: 125-157.
13. Trauzettel-Klosinski S, MacKeben M, Reinhard J, Feucht A, Dürrwächer U, Klosinski G. Pictogram naming in dyslexia and normal children assessed by SLO. Vision Res 2002; 42: 789-799.
14. Meng XZ, Zhou XL, Kong RF. Factors influencing Chinese school children′s reading ability: evidence from a parental questionnaire survey. Psychol Sci (Chin) 2002; 25: 544-572.
15. Phillipd MH, Edelman JA. The dependence of visual scanning performance on saccade, fixation, and perceptual metrics. Vision Res 2008; 48: 926-936.
16. Han SH. The global precedence in visual information processing. Acta Psychol Sin (Chin) 2000; 32: 337-347.
17. Zhao W, Fang JM. The focus and development of research on reading disability as cognitive processing deficit. Chin J Spec Edu (Chin) 2004; 4: 43-48.

(Received June 30, 2008)
Edited by CHEN Li-min