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Eye Movement Characteristics of Children with Developmental Dyslexia during Reading

Yulian Jiang
Lvliang Special Education Vocational College of Shanxi Province, jiangyl@piscomed.com

Abstract: Using eye movement recording technology, the eye movement behavior of children with developmental dyslexia and normal children in reading process was studied, and it was found that the eye movement of children with developmental dyslexia in reading process had obvious defects. The specific manifestations are: prolonged fixation time, increased fixation times, increased number of diplopia, shortened saccade distance, increased saccade times, prolonged latency period, and increased error rate of reverse saccade. Future research should further explore the causes of eye movement defects in children with developmental dyslexia in order to reveal the physiological and psychological mechanisms of developmental dyslexia.

Keywords: Eye Movement; Index of Eye; Movement Process in Developmental Dyslexia; Eye Movement Model

1. Introduction

Reading is an important way to obtain written information. Only by reading smoothly can one obtain information efficiently. However, the study found that some children could not read effectively and had dyslexia in the reading process. Dyslexia can be divided into acquired dyslexia and developmental dyslexia. Developmental dyslexia refers to the fact that some children have normal intelligence level and the opportunity to receive education, without obvious neurological or organic injuries, but their scores on standard reading tests are significantly lower than those of ordinary children. Reading disorder belongs to "special learning disorder", especially in the aspects of reading accuracy, fluency and understand ability, and the essence of this "special learning disorder" is neurological [1]. Researchers believe that dyslexia originates from the absence of phonetic components in language [2]. The absence of phonetic components will aggravate children's difficulties in reading comprehension and reduce their acquisition of reading experience, while the reduction of reading experience may hinder children's learning of vocabulary and background knowledge.

The early research on developmental dyslexia originated from Pinyin, which is a research on children whose mother tongue is Pinyin. However, the study of Chinese dyslexia is relatively late. Previous researchers believed that there is no developmental dyslexia in children whose mother tongue is Chinese. However, Stevenson et al. [3] found that developmental dyslexia exists not only in alphabetic writing but also in ideographic writing, and its incidence rate is not lower than that of alphabetic writing such as English. Children whose mother tongue is Chinese also have developmental dyslexia to the same extent as children whose mother tongue is alphabetic writing. Later studies also confirmed this [4]. As a result, researches on developmental dyslexia in Chinese have increased, and it has been found that developmental dyslexia not only contains many symptoms, but also children with Chinese dyslexia may have more than one cognitive defect [5-8].

The eye is a physiological organ for reading activities. By analyzing the eye movement data, we can know what the eye is looking at, and then infer the cognitive processing activities of the human brain. The study found that during reading, normal readers will have a short saccade from left to right, and during reading, they will alternately see and saccade, and occasionally there will be a right-to-left reflex [9-10]. The eye movement characteristics of children with developmental dyslexia in reading process are different from those of normal children, showing abnormal eye movement patterns. [11]

In the Chinese reading experiment, the eye movement pattern of children with developmental dyslexia was also found to be abnormal. By comparison, the eye movement research on developmental dyslexia at home and abroad showed relatively consistent results. By analyzing the specific eye movement indicators of developmental dyslexia, we can further explore its potential cognitive defects. Therefore, it is necessary to sort out these eye movement behavior defects of children with developmental dyslexia.

Based on the results of eye movement research related to developmental dyslexia, this paper evaluates the eye movement patterns of children with developmental dyslexia, finds out the differences and specific manifestations of eye movement patterns between children with developmental dyslexia and ordinary children in the reading process, in order to find out the rules and causes of eye movement patterns of developmental dyslexia and provide reference for future eye movement research and intervention implementation of developmental dyslexia.

2. Index Selection for Reading Eye Movement Research

In eye movement research, researchers usually choose a variety of eye movement indicators for analysis, and there are many kinds of eye movement indicators and classification criteria have their own emphasis. This paper analyzes them according to two different classification criteria of eye movement indicators.

First of all, according to how and when eyes move during reading, eye movement indicators can be divided into two categories, one is spatial eye movement indicators, the other is temporal eye movement indicators [12]; Secondly, according to whether saccades need conscious control, whether they are processed from bottom to top or from top to bottom, saccades can be divided into autonomous saccades and reflective saccades."

2.1 Eye Movement Index in Time Dimension

In the process of eye movement, the time continuity of eyes in various activities and states is very important information. In the eye movement research, the eye movement indexes extracted from the time dimension mainly include fixation duration and saccade duration.

The fixation duration can be subdivided into firstfixationduration, meanfixationdura-tion, totalfixationduration, etc. The duration of saccade can also be divided into saccade latency (saccadiclatency), saccade completion time (saccade latency), etc. The meaning of eye movement index in time dimension is as follows:

The duration of the first fixation refers to the duration of the first fixation of the eye in the region of interest. gaze time refers to the sum of gaze time of the eyes for many times staring at the region of interest before the first gaze passes.

Total fixation time refers to the sum of all fixation times of the eye to a region of interest, including the time of return [13]; In the region of interest, the average value of the sum of all fixation times is the average fixation time. Some studies have found that although the average fixation time cannot well reflect the real-time process of time processing, it can well reflect the overall situation of reading processing in the overall analysis, [14]. The latency period of saccade refers to the time between the appearance of the stimulation target and the saccade of the eye to the target. The saccade completion time is the time between the eye leaving the fixation point and selecting a new fixation point.

2.2 Eye Movement Index in Spatial Dimension

In addition to the time dimension, there is also an eye movement index with the spatial dimension as the classification standard, that is, where the eye chooses to gaze. The eye movement indexes of the spatial dimension extracted in the study include: gaze position, number of times to gaze at this position (number of times to gaze), distance to jump to this position (eye jump distance), number of times to go back to gaze at this position (number of times to look back). Spatial dimension indicators have the following meanings:

gaze position refers to the position where eyes choose to gaze during reading.The position that has not been watched is jumped.The number of skip reads means the number of times not being watched.

Number of fixations refers to the number of fixations on a location (region of interest), or the total number of fixations on a region of interest. Some studies have found that reading difficult materials or unfamiliar materials and reading simple materials or familiar materials respectively will produce more fixation times, which indicates that when

subjects read materials with high cognitive load, fixation times will increase [15]. The number of times of gaze (regressioncount) refers to the phenomenon of moving eyes from right to left to gaze at the content that has been watched during reading.

saccade (saccade) refers to the jump of the eyeball between fixation points. The saccadic distance (saccadiclength) refers to the spatial distance between two fixation points before and after saccade in a single saccade.The small saccade distance indicates that the subjects get less information in a single fixation, have certain difficulties in reading and understanding the materials, have lower reading efficiency and slower reading speed[16].

2. 3 Reflective Eye Jump Index

Ocular hops can be divided into reflexivesaccades and voluntarycontrolofsaccades according to whether conscious control is needed. Reflexive saccade refers to saccade caused by external new and different stimuli, and is a bottom-up process without conscious control [17].

Reflective saccades include saccades, and the commonly used eye movement indicator is saccadiclatency, i.e. target stimulus from

The time interval between the presentation and the first time the subject makes an eye jump pointing to this stimulus.

2. 4 Autonomous Eye Jumping Index

Autonomous saccade refers to saccade that is not affected by external stimuli, originated from brain instructions and is a top-down processing process that requires conscious participation [18]. Common autonomous saccade has reverse saccade (antisac-cades), and common indicators include reverse saccade latency (anti saccade latency), reverse saccade error rate (anti saccade eserrorate). Reverse saccade means that when the target appears, the subject's eyes will jump in the opposite direction to the target's appearance position. The completion of reverse saccade requires a series of complicated cognitive processing processes, including inhibition of reflex saccade and planning and execution of reverse saccade. The most important thing to complete a correct reverse saccade is to inhibit reflex saccade. Therefore, reverse saccade is one of the effective paradigms to study inhibition ability [19].

Reverse saccade error rate refers to the percentage of saccades in the total number of saccades in which the subject cannot inhibit reflex saccades and makes wrong direction when visual stimuli suddenly appear in the reverse saccade task, which reflects whether the subject can control reflex saccades better and mainly reflects whether the subject has superior saccade control capability [20].

3. Manifestations of Abnormal Eye Movement Patterns in Children with Developmental Dyslexia

Summing up previous eye movement studies of children with developmental dyslexia, it is found that compared with ordinary children, children with developmental dyslexia have many problems in eye movement.

3. 1 Pattern Anomaly Based on Eye Movement Indicators in Time and Space Dimensions

Maria and et al. [21] found that in short passage reading, children with developmental dyslexia have significantly prolonged fixation time, and the fixation times of each word are times of ordinary children’s 2 Hutzler and Wimmer [22]. In the study of text reading and pseudoword reading experiments, it was found that the total fixation time and fixation times of children with developmental dyslexia were significantly higher than those of ordinary children, and the average fixation time was about twice as long as that of ordinary children. Li xiuhong et al. [23] found that children with developmental dyslexia have longer average fixation time and more fixation times. Then, Li xiuhong et al. [24] tested children with developmental dyslexia on picture recognition tasks, and the results were consistent with those before. the first fixation time and average fixation time of children with developmental dyslexia were longer, and the difference was statistically significant compared with ordinary children. Huang Xu et al. [25] conducted three rapid naming tests on children with developmental dyslexia and ordinary children. The results showed that the average fixation time of children with developmental dyslexia was prolonged and the fixation times were increased. Suixue et al. [26] research

found that children with developmental dyslexia have significantly longer total fixation time than normal children, and the fixation times are significantly more than normal children. Deans and others [27] By analyzing the eye movement tasks of children with developmental dyslexia and ordinary children, reaction time tasks, cognitive ability tasks and eye movement data in reading process, it is found that children with developmental dyslexia have long fixation time and more fixation times.

Generally speaking, compared with ordinary children, the study found that children with developmental dyslexia showed abnormal eye movement pattern. with long fixation time, more fixation times, long fixation time, high video rate in terms of eye movement indexes in time and space dimensions. This article speculates that the word processing activities of children with developmental dyslexia occupy a dominant position in the reading process, thus the fixation time is longer. While ordinary children are dominated by the overall processing mode, so the fixation time is shorter. It can be seen that the prolonged fixation time of children with developmental dyslexia may be related to paying more attention to word processing and failing to better integrate contexts. In addition, in the reading process, the main meaning of a word is activated first, and the secondary meaning is activated later. Long-term gaze will cause the secondary meaning to be activated again, which will interfere with the reading comprehension of the subjects and reduce their reading efficiency[28]. In a word, the longer fixation time is caused by the defects of word decoding and context integration of children with developmental dyslexia, and the longer fixation time interferes with the reading of children with developmental dyslexia again. The increased number of fixations, has a higher rate of video recall, which reflects that children with developmental dyslexia have a greater cognitive processing load on reading materials, indicating that they cannot effectively understand reading materials, and of course it may also be caused by their low reading level.

3. 2 Pattern Anomaly Based on Reflective Eye Hop Index

Biscaldi and et al. [29] divide developmental dyslexia into short-term memory defect and reading / writing defect. It is found that the saccade pattern of both groups of developmental dyslexia patients is abnormal, which is manifested by significantly prolonged reaction time and saccade latency. Maria and others [30] analyzed the saccade patterns of children in developmental dyslexia group and children in general group in non-verbal test and verbal test tasks. The results showed that children in developmental dyslexia group showed the phenomenon of smaller saccade distance and more frequent saccade times in verbal test. Later, Maria and others [31] also found that children in developmental dyslexia group had the same abnormal saccade pattern on real words and fake words, showing a small saccade distance, frequent saccade phenomenon. Bucci and et al. [32] When studying compound saccade and divergent saccade, it was found that the saccade latency of children in developmental dyslexia group was longer than that of children in normal group.

To sum up, children in the developmental dyslexia group all experienced, frequent saccade times, abnormal saccade pattern with long saccade latency. In the experimental process. According to the characteristic of short saccade distance, frequent saccade times of children with developmental dyslexia, children with developmental dyslexia can obtain less information and have smaller perceptual span at one saccade, and their reading is localized / word processing, not holistic / sentence processing. Therefore, children with developmental dyslexia using small saccades will not only affect the context integration ability of materials, but also affect the speed and efficiency of reading comprehension.

3.3 Pattern Anomaly Based on Autonomous Eye Hop Index

Luna and Sweeney [33] found that ordinary subjects had a high error rate in completing the reverse saccade task, which was almost 50% to 60% of the total number of trials. Unsworth and et al. [34] Studies have found that when ordinary subjects are fully trained, there is no significant difference between the correct rate and latency of reverse saccade and the correct rate and latency of forward saccade. However, Biscaldi and others [35] found that children in developmental dyslexia group made more mistakes in the task of reverse saccade, and their scores were one standard deviation lower than those in normal group, and their control ability of reverse saccade was impaired. Lukasova and others [36] experiments show that the error rate of reverse saccade for children in the general group is in the range of 50% to 60%, and children in the developmental dyslexia group not only exceed this range, but also show the phenomenon of longer saccade latency, lower accuracy rate of reverse saccade. Fischer and others [37] found that in the three

visual detection experiments, children in the developmental dyslexia group and children in the general group had significant differences, which was lower than one standard deviation of children in the general group, especially in the reverse saccade task. Wang Jingxin et al. [38] studied the saccade performance of children with developmental dyslexia and children in the general group under the condition of internal and external cues. The results showed that the correct saccade latency of children with developmental dyslexia was longer than that of children in the general group, which indicated that it needed longer time for saccade preparation. Not only that, the children in developmental dyslexia group have a higher error rate of reverse saccade, and reach significant margin with the children in normal group.

According to the above documents, children with developmental dyslexia have long latency of reverse saccade, saccade behavior defect with low accuracy of reverse saccade. Reverse saccade task is a powerful tool to study cognitive process, which is helpful to explain the cognitive operation differences between some special mental patients and common subjects. First of all, the high error rate of backward saccade in children with developmental dyslexia indicates that children with developmental dyslexia are more likely to have saccade towards the eye than backward saccade, and their eye movement control system may have defects and cannot effectively control their eye movement behavior. Secondly, the longer latency of reverse saccade indicates that children with developmental dyslexia need longer time to inhibit saccade towards eyes and have weaker ability to inhibit processing. The defects of saccade control and inhibition may hinder the reading processing of children with developmental dyslexia.

4. Future Research Prospect

Eye movement is ubiquitous. Influenced by the gradual maturation of cerebral cortex and the nerve reorganization process in the eye movement nerve control area, the eye movement behavior of children and adults is quite different. Therefore, whether some experimental conclusions based on adult subjects are applicable to children remains to be discussed. Therefore, it is necessary to systematically study the eye movement of children with developmental dyslexia, "by analyzing different eye movement indexes.

First of all, the quantitative screening criteria for developmental dyslexia are very important. Based on the complexity of the reading process and the high heterogeneity of children with developmental dyslexia, researchers differ greatly in the criteria for screening children with developmental dyslexia. Due to the heterogeneity of cognitive ability and the uncertainty of the probability relationship between cognitive impairment and dyslexia, it is inappropriate to screen dyslexia using any one of the known cognitive data. Although no research results show that developmental dyslexia is caused by abnormal saccade pattern, it is obvious that the saccade pattern of children in developmental dyslexia group is inconsistent with that of children in normal group. Therefore, whether quantitative criteria can be made for screening children with developmental dyslexia from the perspective of eye movement, that is, whether screening criteria for developmental dyslexia can be formulated based on saccade index, is a question worthy of study. Different from the previous qualitative screening criteria, the advantage of taking eye movement index as the standard is that it can avoid the judgment standard deviation caused by cultural background differences caused by regional, language, education and other differences. Researchers can judge whether the subject suffers from developmental dyslexia by observing whether the abnormal eye jump pattern meets the judgment standard, thus making the research on developmental dyslexia more accurate, comparability and popularization.

Secondly, the possibility of developing dyslexia can be tested through eye movement experiments at all ages and even at the early infant stage, and intervention can be implemented. For example, we can observe infants' saccade behavior to sound stimulation or picture stimulation, check whether their eye movement indexes such as, number of retraces, latency period of eye movement are normal, screen and diagnose, implement early intervention to infants with potential risks, and achieve early detection and early correction. Early diagnosis and intervention of developmental dyslexia are very important, especially in early childhood. However, it is difficult to screen dyslexia from the perspective of cognitive processing, but eye movement method has unique advantages.

Finally, future research needs to further solve the problem of differences in cross-language research. Many psychological studies have found cross-cultural differences, and it is likely that developmental dyslexia also has differences.

However, summarizing the previous literature, we can find that, in children with developmental dyslexia undoubtedly has abnormal saccade patterns, and shows the same trend in most saccade indicators. The possible reasons are as follows: first, children with developmental dyslexia are affected by processing defects at linguistic level, and there are cognitive processing defects in the processing and representation of speech information, while cognitive processing defects are common in and children with external developmental dyslexia. Most researchers believe that " developmental dyslexia is caused by speech core defects " [39]. In addition to English, German studies also show that some children with developmental dyslexia are also significantly behind their peers in fast naming tasks[40]. In the Chinese language constructed by pure symbolic characters, children with developmental dyslexia in Chinese also have phonetic consciousness defects and rapid naming defects [41] ,which all show similar characteristics to children with developmental dyslexia in the phonetic character system. It can be inferred that similar cognitive skill defects in reading process may be the cause of abnormal similarity of eye movement index in children with developmental dyslexia at home and abroad. Second, children with developmental dyslexia are affected by non-linguistic processing defects[42-43], such as the relatively consistent expression in Chinese and English studies that developmental dyslexia is affected by visual macrocell pathway defects, which reflects the cross-linguistic consistency of macrocell pathway defects[44-45]. In the previous research on visual perception of developmental dyslexia, the results are consistent, which is reflected in relatively consistent results on eye movement indicators. Third, although children with developmental dyslexia have subtypes [46], and the subtypes of developmental dyslexia in Chinese and English may also be different, in the process of experiments at home and abroad, the rest of the research experiments did not strictly distinguish children with developmental dyslexia except for the literature aimed at exploring subtypes differences, which may also be one of the reasons for the convergence of eye movement research results at home and abroad.

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