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Eye-Tracking Researches in Reading and Second Language Acquisition: from Monolinguals to Bilinguals

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Abstract:

The mechanism of cognitive processing in reading has been a research focus for many years. Recent years, people have gradually turned their focus from understanding the process of text of monolinguals to bilinguals. As eye-tracking technology becomes more and more sophisticated, this paper aims to selectively review studies employed eye-tracking in reading and second language acquisition and to provide advice for Chinese learners of English. Based on CNKI and Web of Science database, this paper reviewed classic research in eye movement and eye-tracking, and analyzed research in reading and second language acquisition by areas of interest. Then, this paper summarized research focus, and particularly the factors influenced reading ability in passage reading. Moreover, the paper pointed the limitations of previous research and found two general problem: the limited participants and eye movement measures. Finally, this paper considers future directions for both monolingual and bilingual studies and in particular the language comprehension mechanism.

Keywords: Eye movement; Reading; Second language acquisition.

1. Introduction

International communication has been facilitated by globalization. Every nation‘s language is a direct representation of its culture. Acquiring proficiency in their languages is vital for mutual appreciation and improved global communication. Therefore, it is of great importance to learn a foreign language. Reading is the most important of the four language acquisition sections—listening, reading, writing, and speaking. Reading written materials from different nations allows one to comprehend the cultural background of all ages. One could argue that reading is a concise approach to learn about another culture without leaving doors. Furthermore, an individual‘s reading style is indicative of how they assimilate information. By comparing the pattern differences between native speakers of different languages, the cultural differences of different native speakers can be explored. By exploring the differences in reading patterns between native speakers and second-language learners, the language level of second-language learners can be inferred. Comparing two languages, one of the differences between written Mandarin Chinese and English is that Chinese characters are ideograms while English letters are phonograms. Hence, there must be differences in the information processing of two language materials, explicit by eye movements. Moreover, it is generally agreed that learning a language from an older age is more difficult than in the early stages. College students, as one of the populations of adults, are language learners with various backgrounds and language proficiency, thus providing plentiful data.

To help second language learners become more proficient readers, more thorough research on English reading college students who are native speakers of Chinese is therefore required. By using eye-tracking technology, researchers can effectively analyze the subject’s cognitive process in discourse comprehension, find the inherent causes and mechanisms of reading, and hence propose effective suggestions for reading strategies.

Eye tracking technology is recording eye movements to know exactly where a person is looking and for how long [1]. Nowadays, Eye trackers measure the eye position, movement, and pupil size at a specific time to detect the interest areas of the user [1]. As a research tool, eye-tracking is becoming widely available and well-liked by researchers from different disciplines. In clinical areas, several studies focused on the production of children with specific language impairment (SLI) [2, 3], and eye movement disorders caused by neurological diseases [4]. In industrial areas, studies of user experience, consumers’ attention, web usability, etc. were conducted.

The study of eye movements has proven to be one of

the most successful approaches in research on reading [5]. Previous research on eye movements in reading was conducted from three partially overlapping perspectives: visual processing and sensorimotor control, word-level processing, and psycholinguistics hypotheses about the processing of written language [5]. Based on CNKI and the Web of Science database, the research will review eye-movement-based experimental reading studies from China and other countries during the 21st century, in order to foster more effective learning and teaching approaches for English learners of college students. By delving into current research on eye movements, this paper aims to review achievements and theories developed during the last twenty years and to explore their application in improving English reading ability among Chinese college students.

The introduction includes background information and the significance of using eye-tracking technology to explore the second language reading process. The Literature Review will review major studies from three partially overlapping perspectives: eye movements, reading ability, and second language acquisition. In Analysis, the paper will discuss the possibility of using eye movement findings to improve the reading ability of second language learners. Finally, the conclusion will briefly summarize previous research findings and their practical uses.

2. The Development of Eye Tracking

This section is divided into three parts. The first is eye movements and eye tracking technology. The second is previous research on reading Chinese and English. The third is previous research on reading and second language acquisition.

2.1 Eye Movements and Eye Tracking Technology

There are three basic types of eye movements (EMs): fixation, saccades, and smooth pursuit movement. The activity of aligning the eyes with the object is called fixation. Saccades are rapid, ballistic movements of the eyes that abruptly change the point of fixation [6] and occur in reading, watching a scene, or looking for an object [7]. During fixations, one's eyes stay fixed for about 200-300 milliseconds between saccades[7]. Smooth pursuit movements are much slower tracking movements of the eyes [6]. Fixations and smooth pursuit movements are designed to keep stimulus on the fovea [6]. The difference between the last two types is that smooth pursuit movements are under voluntary control in the sense that the observer can choose whether or not to track a moving stimulus. At the same time, saccades can also be made unconsciously [6].

2.1.1 Development of Eye-tracking Technology

Eye tracking technology records eye movements in time and space, such as duration, time, and fixation point. Initially, people recorded eye movements through observation. In 1759, Porterfield described eye movement without empirical evidence [8]. In 1900, Dodge employed an assistant to observe the eyes of another person to avoid the distrust of subjective experience [8]. In the 19th century, researchers were also trying to invent mechanisms. The auditory method and distance method was invented. In 1879, Lamare and Hering employed an auditory method separately [8]. Distinctive sounds represented different EMs. In 1878, Rählmann invented a distance approach [8]. EMs could be registered by the displacements of the bristle on a revolving smoked drum [8]. Huey refined the technique by stabilizing the head and was able to register discontinuous eye movements during reading [8].

As the 20th century began, there was a proliferation of eye-tracking technologies. Photographic devices that required no attachment on the eye and that were more comfortable for the participants were developed by Dodge [8]. However, that was still inexact for resolving tiny eye movements. Based on the invention of the photoelectric sensor, eye trackers developed in the late 19th and early 20th centuries provided tools with higher accuracy and more directness of eye movements. Nowadays, eye-tracking systems can measure eye position, movement, and pupil size at a specific time to detect the interest areas of the user [1].

From subjective to objective, researchers keep exploring eye tracking technology. With their efforts, people were able to discover the nature of human cognition.

2.1.2 Importance of Eye-tracking in Cognitive Processes

Eye movements (EMs), as an eliciting representation of human thought's workings, express human's cognitive process. The allocation of human cognitive resources, whether active or passive, and the selection of more appealing or helpful information constitute the essence of eye movement.

People have always been curious about how the brain works. Nowadays, researchers can find the answer to this question through various technological means. Eye movements reflect the visuomotor output of complex and dynamic interactions between numerous brain regions. This distributed brain network, required for eliciting eye movements, provides a powerful research tool to investigate the working functions of one of the most complex organs: the brain [9].

The eye-mind hypothesis suggests that there is a relationship between fixations and what people are thinking about, revealing the significance of eye-tracking data [10].

An element's duration of attention is directly correlated with the information it contains [10], which means that the longer one looks at the object, the more information it contains. As a theoretical framework, the Eye-Mind Hypothesis helps to understand the relationship between eye movements and cognitive processing during reading.

Numerous studies about visual dominance support the notion that vision is, in fact, the most essential modality [11]. Visual input frequently predominates over other modalities in perceptual and memorial reports and in speeded responses. It seems that visual dominance is associated with the comparatively low ability of visual inputs to notify the organism of their presence [12].

2.2 Reading

Generally, there are two ways of assessing reading ability. Traditionally, people use off-line measurements. Teachers employed exams to see whether students understood the text. Researchers employed paradigms like self-paced reading to explore the processing of information in humans. Through the development of technology, online measurements, such as eye tracking, were widely used to explore the real-time process of reading comprehension of readers. Four or five saccades occur every second during the reading process, even though people's conscious experience of reading is scanning the lines fairly smoothly and continuously [13]. There is a belief that the fovea, as the small circular space of maximal visual acuity, can only identify one or two short words with each fixation [13]. Based on the eye-mind hypothesis, the reason why a person's eyes constantly move during the text is that they need to align the fovea with new information in order to understand it.

The eye-tracking technique was invented and is well-explored in Western countries, as discussed in the section above. In China, based on the CNKI database, eye-tracking technology was used in the 1980s, and the real improvement of using it for reading comprehension was until the 2000s, though E. Shen was the first Chinese researcher to use this technology at Stanford University.

2.2.1 Chinese Words and the Basic Processing Unit

At the word or character area, eye tracking was widely used to explore issues with lexical identification. In an alphabetic written system such as English, there are spaces between two words, which provide unambiguous visual evidence of word boundaries. In contrast, Chinese text is normally printed as a continuous string of characters. Also, word formation is flexible; that is, 2-character words are most common, but one, three, or more adjacent characters can also comprise a word. Some people regard what others perceive as words as phrases. Hence, the definition of words has been argued a lot, which has led to several issues. Eye-tracking was widely employed in this area.

One important issue is about the basic processing unit. Research in English has generally confirmed that words are the basic processing unit. However, as the Chinese lack space markers, people have failed to reach a consensus on what the primary unit of information in Chinese reading is. Previous studies proposed the possibility of word or language chunk as the answer. Further, from the word level, researchers discussed the possibility of psychological words and prosodic words. Researchers found that psychological words were easier to process than character, normal, and nonwords [14]. The study examined the presence of psychological words while reading texts and the differences in eye movement indicators among participants under different segmentation methods. The advantage lies in examining the same subject after six months. The disadvantage is that the number of participants selected is relatively small, only 20 [14]. Later, researchers suggested that the prosodic word, under the slow reading condition, is the smallest prosodic unit that can be accepted by the readers and within the reader's perceptual span and is thus more likely to be the basic processing unit in Chinese sentence reading [15]. The researchers used twenty volunteers to decide the word boundary of the slow reading condition. However, the study only focused on sentence level, which may be too easy to process. A different result may be obtained if passages are used as materials. Recent studies about language chunks focused on Teaching Chinese as a Second Language (TCSL) instead of on native speakers. More studies were needed to explore whether language chunk is an effective way for native Chinese speakers to process sentences. Clear definitions of these concepts still hang in doubt. These findings indicated that the basic processing unit in Chinese sentence reading is in larger than words.

2.2.2 Relative Clauses and Language Comprehension

At the sentence level, Relative clause (RC) is a worldwide research topic in sentence processing. Research in relative clauses was viewed as a helpful tool to explore language comprehension. For English studies, recent eye movement research on the processing of pronominal relative clauses supported memory-based theories as a more important role in sentence comprehension [16]. According to the antecedent, Chinese relative clauses can be divided into subject relative clauses (SRC) and object relative clauses (ORC). Chinese researchers put more effort into which type of RC in Chinese takes advantage of processing. The existing research on the relative clause suggested that there is a processing asymmetry between SRC and ORC. However, there have been disagreements on which type of

attributive clause is more advantageous in processing. The study that employed eye tracking shows processing preferences of subject relative clauses [17]. However, some of the sentences used in the experimental materials are not based on language corpus; that is, they are created for controlling variables, which may have an impact on the experimental results. The result of the processing advantage of SRC is consistent with the study on the processing of RC in Indo-European languages.

2.2.3 Reading Ability

At the passage level, studies generally focused on what affects reading ability. From the participants' perspectives, one research hotspot is the role of morphological awareness in improving reading ability. Previous behavior studies suggested that morphological awareness has a promoting and predictive effect on language learners' reading comprehension skills [18]. One study employed behavior methods and found that morphological awareness helps in facilitating the Chinese reading ability of primary school students [19]. The experiment recruited 247 participants, making the results more universal. Eye tracking was seldom used in this area, which suggested further research was needed.

From the materials' perspective, the influence of reading medium on reading comprehension was well discussed. Previous behavior studies revealed that reading comprehension on paper is better than on digital devices among all ages, which is consistent with one's common sense. One meta-analysis study suggested that while handheld devices seem to provide a reading experience that is closer to printed books than that of computers, they still negatively affect comprehension [20].

Moreover, the impact of information carriers on students' cognitive understanding is greater than that of reading test scores. Digital reading achieves better results at lower cognitive levels, such as surface understanding and semantic understanding [21]. However, this was contrasted with one eye-tracking study, which only found significant differences in eye movement patterns between different literary forms but not in reading medium [22]. The study only analyzed the number of fixations and total reading time and ignored other eye movement measures. The cognitive processing of reading between paper reading and digital reading needs to be further discussed.

2.3 Reading and Second Language Acquisition

Many studies have revealed a positive correlation between the amount of reading and English proficiency in EFL students [23]. Hence, a lot of research efforts have been devoted to second-language reading. In this field, researchers mainly focus on two issues: how bilinguals process vocabulary and grammar in a second language and the factors that influence bilinguals' second language reading ability.

2.3.1 Lexical and syntactic disambiguation processing of second language

Many studies focused on the processing of ambiguity in order to reveal the second language processing of bilinguals. Eye tracking was widely used in this area since it reflects direct cognitive action.

At the phrase and sentence levels, in China, some studies explored lexical disambiguation by word class. One eye-tracking study focused on demonstrative pronouns and suggested that the impact of referential ambiguity on pronoun processing should be explored differently at early and late stages [24]. The study analyzed five eye movement measures to better infer cognitive processing in disambiguation. The materials were sentences that raised a query about pronoun disambiguation in the text.

At the syntactic level, researchers mainly focus on the ambiguity of relative clause attachments and garden path sentences. One study found that Chinese learners of English show different preferences for RC attachment with native English speakers [25]. When processing sentences like "NP1 of NP2", L2 learners with higher working memory spans tended to attach the RC to NP1 [25]. When processing sentences like "NP1 with NP2", L2 learners with lower working memory span tended to attach the RC to NP2 [25]. The result suggested that Chinese learners of English with higher working memory span prefer predicate proximity, which is inconsistent with the preference of native speakers [25]. The disadvantage of the study is that it only tested 36 participants, which is a relatively small number of students. The other research focused on English "direct object/ subject" garden path sentences and found that L2 proficiency levels influence garden path effects in the disambiguation verb region across late processing stages [26]. By analyzing regression path reading time, the study suggested that L2 learners with higher language proficiency tend to reconstruct garden path sentences by using syntactic rules [26]. The study has the limitation of classifying language proficiency simply based on vocabulary tests.

2.3.2 Bilinguals' second language reading ability

Many studies have been devoted to exploring variables that influence second language reading ability. Eye-tracking was widely used in this field. From the participants' perspectives, Chinese researchers mainly focused on students with different levels of proficiency in English. One study explored different eye movement patterns between college students of higher and lower proficiency [27].

Students with higher proficiency presented shorter fixation times, fewer numbers of fixations, and large saccadic amplitude [27]. The work is limited to defining language proficiency, as researchers simply used test scores.

From the perspectives of the reading materials, the influence of reading style was explored. The study mentioned above also explored the effects of reading style on college students'English reading comprehension [27]. The number of fixations during reading expository texts is significantly less than that in argumentative essays [27]. The study asked participants to answer multiple-choice questions in order to test their comprehension of the text [27]. The approach may lead to an answer-interested reading strategy. Hence, its eye movement patterns may be different from those of natural reading. Also, this work suffers the same limitations as it involved too few participants.

3. Summary

3.1 Research of Eye Movements

In general, eye-tracking techniques are currently being used more often in studies to examine the influence of reading carriers and individual differences in their reading ability in both native language and a second language. The impact of reading modality on reading comprehension has been widely discussed because digital reading is becoming increasingly popular with the development of the technology. In addition, the impact of individual differences on reading ability has also received widespread attention. Researchers have investigated the variations in eye movement patterns among readers across various ages, native languages, majors or careers, and level of language proficiency. Specifically, in the research of Chinese language, people pay attention to the basic processing unit and the processing advantage of relative clause. The basic information unit in Chinese was thought to be words or language chunk and was still unclear. People once attempted to add spaces between words to study this issue, but this approach was abandoned due to the participants not adapting to this form in a short period of time. The processing advantage of subjective relative clauses was supported by eye-tracking studies. In the research of second language acquisition, people pay attention to the lexical and syntactic disambiguation in order to explore how bilinguals process a second language.

3.2 Previous Research Limitations

As one of the modern technologies, compared to traditional behaviour approaches, eye-tracking methods itself has the advantage of reflecting cognitive process. However, when comparing to electroencephalography, it has the shortage of reflecting only surface action of human and can be controlled consciously. By recorded event-related potential, one can identified whether the phenomena are more related to semantic or syntax, which is something that cannot be intuitively reflected by analyzing eye movement measures.

As for experiment design, previous work showed several limitations. The first is, the number of participants was relatively small. This is understandable since the difficulty of recruiting participants is a problem faced by nearly every researcher who conduct empirical research. The second is classifying subjects in a traditional and inflexible standard. Researchers generally divided participants by their test scores, yet the mark may not completely reflect one's language competence. The third is the naturalness of the materials. Some studies employed materials that may not accepted by people, that is, people may not use them in daily activity. The fourth is the lack of context. When focusing on lexical and syntactic processing, the materials often are sentences. Since the length of reading may affect information process, it is of great importance to put the area of interest into context. The fifth is the examination form of reading comprehension. Researchers generally uses exam questions to test whether the participant understand the text, which faced the same shortage of the second limitation. Moreover, this form may lead to a different reading strategy from the natural reading. The sixth is the insufficient analysis of eye movement measures. Most research only analyzed number of fixations and duration times. The seventh is, in research on second language acquisition, people pays more effort on explore merely second language learners. In fact, there is less research compared the eye movement pattern of both L2 learners and native speakers in reading the same material. Consequently, the difference between them may not be well-explored.

3.3 Future Directions

Based on the characteristic that eye-racking technology can directly reflect human cognitive activities, research on this field will continue to focus on the theories drawn from experiments using traditional methods and verify their correctness.

For research of Chinese, the area saw as offering future promise is the verification of previous speculations on specific structure processing, for instance, phrases and relative clauses. Eye-tracking can help to verify the relationship between words, that is, what kind of phrase it is. For example, people keep wondering the phrase (1) below is a adverbial head word modifying construction or is a verb complement structure:

(1)Zuo zai yizi shang

sit-V on-P chair-N top-P

sit on the chair

By comparing the eye movement with certain types of phrases, one can reveal that the structure that one focused is more closer to which type. Moreover, it may be useful to study the basic processing unit of Chinese, as it can help to understand the information processing of Chinese and to better teach Chinese as second language.

For research on second language acquisition, more investigation is required on understanding the mechanism of bilinguals, for instance, the lexico-semantic representations and lexico-syntactic representations. Previous studies supported different models for this topic. Some researchers even suggested that the processing in early and late stages may be different. In future work, it may be useful to study individual development stages as eye-trackers can be easier to obtain than ever. The traditional exam used to assess language competence is not that accurate. One study suggested that analyzing early readers' natural eye movements could help inform assessments of reading development in the educational setting [28]. Moreover, further studies are required for causes and solutions of fossilization in second language learning. Fossilization has been widely discussed in second language acquisition from the perspective of linguistics and psychology. Age, social identity and communicative need, etc. are considered as the factors that influenced "succession" of language learners. By employing eye-tracking and compared the pattern difference with native speakers at the same language development stages, one may find the method to cease fossilization.

From the perspective of experimental methods, the future research trend is combining eye-tracking with electroencephalography, in order to deeply explore the human cognitive process. In addition, there is a trend that sharing eye movements data to the public, for instance, the GECO-CN corpus [29] and one corpus that contains nine eye-movement measures of a large-scale eye movement study [30]. The eye movements corpus will greatly facilitate future research as it provided secondary data for researchers and helps readers better understand the eye movements patterns of participants.

4. Conclusion

The review of classic papers in eye movements and eye-tracking technology shows that eye movements has been studied for centuries. As vision is a important modality, eye movement were thought to be a explicit reflect of human cognitive process. Recent years, eye movement experiments in reading and second language acquisition shares an common focus: what influenced reading comprehension. Particularly, studies in Chinese focused on the basic processing unit and relative clauses processing. Studies in second language acquisition focused on the lexical and syntactic disambiguation process. Moreover, there are several limitations for those experiments: the number of participants, classifying subjects in a traditional and inflexible standard, the naturalness of the materials, the lack of context, the examination form of reading comprehension, the insufficient analysis of eye movement measures, and lack of comparing native speakers and L2 learners. By analyzing prior works, the paper provided several future directions. In studies of Chinese, specific structure processing and the basic processing unit requires more research. In studies of second language acquisition, language comprehension mechanism for bilinguals, individual developmental stages, and causes and solutions of fossilization requires more research. This work provided references for eye-tracking experiment in reading and second language acquisition. The study is beneficial for stimulating future researchers' research interest. Furthermore, this work is constrained by limited number of eye movement research. With the wide spread of eye-tracking technology in multiple topics, the review on this topic will be improved.

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