Eye Movement Studies in China

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■ 主　　编 白学军 闫国利

眼动研究在中国

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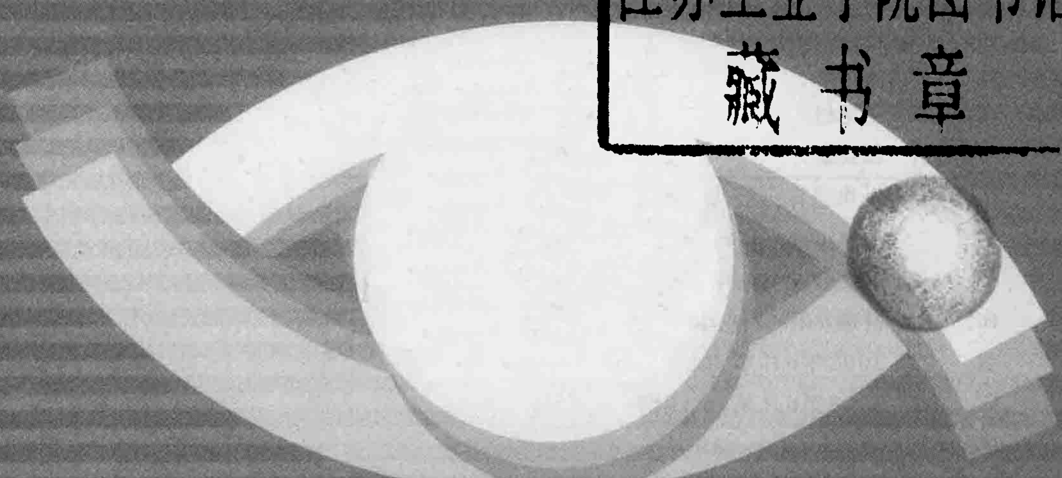

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序

眼睛是心灵的窗户,通过记录和分析人们阅读时的眼睛注视过程,能深化我们对人类认知活动本质的认识。

关于眼动的心理学研究开始于19世纪末,从那时起,就成为心理学家研究兴趣之一,同时也成为国外心理学研究中的热门领域。

由于各种原因,我国在这个方面研究比较少,起步也比较晚。在20世纪五六十年代,国内只有几项眼动研究的心理学报告。进入20世纪80年代以来,我国一些大学的心理系、教育系和科研机构陆续从国外购进了眼动仪,并初步开展了一些研究工作。目前,国内心理学工作者在眼动研究领域已经取得令人可喜的成果。

为了推动国内眼动研究的发展,加强国内眼动研究领域的专家之间的相互沟通和交往,我认为在中国召开眼动会议也是非常必要的。为此,由我和美国著名眼动研究专家Keith Rayner教授于2004年在教育部人文社会科学重点研究基地——天津师范大学心理与行为研究院发起了中国国际眼动大会。此后,在2006年又召开了第二届。第三届由中山大学心理系主办。事实上,中国国际眼动大会已经成为连接国内外眼动研究专家的一个纽带,同时也将成为专家们交流思想、加强合作的重要平台。在此,非常感谢国外的眼动研究专家为促进中国眼动研究的发展所做的贡献。

天津师范大学心理与行为研究院的白学军教授和闫国利教授都曾是我指导过的研究生,也是我国较早从事眼动研究的青年学者,他们除了致力于研究之外,同时也十分注意促进国内眼动研究的发展问题。现在,他们将国内的眼动研究论文汇集成册并编辑出版。我觉得这样做有两个作用:第一,对国内的眼动研究进行一个总结,以促进眼动研究的进一步发展;第二,该书具有一定的文献价值,特别是对刚刚进入眼动研究领域的同志们,其中不少文章可以起到一个参考借鉴的作用。

随着眼动仪技术的进步,目前我国许多高校和科研单位都已购置或正准备购置眼动仪,中国学者在国内外发表的眼动研究论文数量也逐年增加,越来越多的心理学家开始对眼动研究表现出浓厚的兴趣。我们欣喜地看到,中国眼动研究的繁荣时期已经到来!

沈德立
2008年初春于天津师范大学
心理与行为研究院

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Future Directions for Eye Movement Research

□ Keith Rayner
(Department of Psychology, University of Massachusetts, Amherst, MA 01003, USA)

Abstract It is argued that research on eye movements has now entered a fourth general era. Each of the four eras is briefly reviewed, and research findings related to eye movements during reading, scene perception, and visual search are discussed. Future directions for research in each of these areas and research in other domains involving eye movements are also discussed.

Key words eye movements, reading, scene perception, visual search, information processing tasks.

Eye movement data have proven to be extremely useful in the study of many topics related to cognitive processing. Indeed, they may be the best on-line measure of moment-to-moment cognitive processes. This is not to say that eye movements will prove useful in every aspect of cognitive processing. For example, it is difficult to see how eye movements may reveal a great deal about basic memory processes (but, even here, they could be useful determining exactly what people remember from a scene or visual display). In this article, I will briefly summarize some important findings that have emerged from eye movement research and then I will discuss some possible future directions for eye movement research.

Elsewhere, I have argued[1] that we are now into the fourth era of eye movement research. Because my own research has focused so heavily on reading, it is clear to me that these four eras hold for research on reading. They may not hold as clearly for some other research areas. I will discuss these four eras with respect to research on reading. Later in the article, I will summarize research on eye movements during reading, scene perception, and visual search. When discussing reading, I will primarily focus on English, but wherever possible I will also discuss research on reading Chinese.

The first era of eye movement research began with Javal's observation that the eyes do not move smoothly across a page of text, but rather make the now familiar sequence of fixations (typically lasting 200 ~ 250ms) and sacades (the rapid movement of the eyes, which typically last 25 ~ 40ms in reading). During this era, a great deal was learned about the basic characteristcs of eye movements during reading using, what seem today like, rather crude instrumentation. It is a tribute to the researchers in this era that virtually all of their findings have turned out to be valid despite the crude nature of the eye-tracking systems available. Researchers like Huey, Dodge, and Dearborn were leaders of this era.

The second era coincides with the Behaviorist movement in American Psychology. Whereas those in the first era of eye movement research were quite willing to generalize from the eye movement data to mental processes[2], research on eye movements in reading during the second era tended to be highly descriptive with little attempt to tie the data to underlying mental processes. Researchers like Tinker, Buswell, and Gray were the leaders of this era.

The third era began in the early 1970's, and was largely motivated by the development of the gaze-contingent display change paradigm[3-5]. This era also coincides with the rebirth of Cognitive Psychology in the United States[6]. With respect to reading, just prior to this time there were impormant developments within the field of Linguistices that resulted in a better description of language than was available previously. It is instructive in the present context that in the last of a series of reviews that he published, Tinker concluded that "The future study of eye movements in reading does not appear to be too promising. The eye-movement approach to the study of reading has probably made its major contribution"[7]. I will not go into the reasons that may have led Tinker to this rather pessimistic conclusion. However, it is clearly the case that he was wrong, and he was wrong because he could not anticipate the technological advances that were just around the corner with respect to better and more efficient eye-tracking systems and a better understanding of language. During this third era, a great deal was learned about eye movements and basic mental processes during reading[1,8-10].

The fourth era coincides with the development of sophisticated models which effectively simulate eye movements during reading. Perhaps the most prominent of these models is the E-Z Reader model[11-13]. Other recent examples are Mr. Chips[14], Glenmore[15], SWIFT[16-17], EMMA[18], and the Competition/Interaction model[19,20]. The virtue of these models is that they are able to not only simulate the characteristics of eye movements in reading[13], but they also have generated a considerable amount of research that otherwise might not have occurred. This happens typically because of the precision of a model which leads to testable predictions[13].

As I noted at the outset, these four eras describe research periods with respect to eye movements and reading. It is the case that other areas in which eye movements have been used to investigate mental processes may not have quite the same history as reading, but the similarities are greater than the differences. At this point, I will describe the characteristics of eye movements in various tasks. After that, I will briefly summarize the primary findings for reading, scene perception, and visual search.

Eye Movements in Various Tasks

Table 1 provides a summary of the primary characteristics of eye movements across a number of different tasks. Here it can be seen that the average fixation duration varies quite a bit as a function of the particular task. In silent reading, the average fixation duration tends to be roughly 200 ~ 250ms, while in oral reading it increases to more like 300ms for readers of English. Fixations also tend to be longer in scene perception, music reading, the average fixation duration tends to be highly variable and is very much influenced by the density of the array and search difficulty.

Table 1. Average fixation durations (in milliseconds) and saccade length (in degrees of visual angle) for a number of tasks.

Task	Fixation Duration	Saccade Length
Silent reading (English)	200 ~ 250	2deg (8 letters)
Silent reading (Chinese)	200 ~ 250	2deg (2.0 ~ 2.6 letters)
Oral reading (English)	275 ~ 300	1.5deg (6 letters)
Scenes	300 ~ 330	4deg
Visual search	190 ~ 275	3deg
Music reading	375	1deg
Typing	400	1deg (4 letters)

Note that in reading, number of letters is a more appropriate measure of saccade length (see Rayner, 1998). Thus, for the reading related tasks, the number of letters is also shown in situations where 4 letters equals one degree of visual angle (for English) and 1 letter equals one degree (for Chinese). If the letters were larger, so that in English 3 letters equaled one degree, the saccade size would still roughly 8 letters (but the saccade size in terms of degrees of visual angle would change).

For comparison purposes (and since there is nothing equivalent to letters in the non-reading tasks), the average saccade size is shown in terms of visual angle. However, for reading, it is well-known that letters are the appropriate metric to use in computing saccade size[1]. The values for Chinese readers are taken from Chen, Song, Lau, Wong, and Tang, and Inhoff and Liu[21,22]. It is interesting that the average fixation duration seems to be similar for readers of Chinese and English. What obviously differs is the saccade size (as determined by number of letters). In the Chen et al[21] and the Inhoff and Liu[22] studies (as well as others I've seen on eye movements of Chinese readers), the average letter size is about. 9 deg (thus, the letters are typically larger than in English). So, if one compares on visual angle, there are similarities with English. But, given that the information is more densely packed in Chinese characters, the average saccade length is considerably smaller when measured in letters. From this, it also follows that the perceptual span in Chinese is smaller than in English[22,23].

A final important note with respect to Table 1 is that saccade size in scene perception and visual search also tends to be highly variable and depends again on the density of the array and the difficulty of the task. However, it is clear that more information tends to be taken in during a single eye fixation for scenes and search than for reading.

What is Known About Eye Movments in Reading, Scene Perception, and Visual Search?

In this section, I will provide a very brief overview of what is known about eye movements in reading, scene perception, and visual search. Given that these three tasks are the ones that have been investigated most frequently, I will devote more attention to them. However, other tasks will be considered later.

Reading

A number of important conclusions have emerged from research on eye movements and reading. More detailed information about each of the following points can be found in Rayner[1]. The important findings and conclusions are as follows:

1. The perceptual span in reading extends from the beginning of the currently fixated word (or about 3 ~4 letters to the left of fixation) to about 14 ~ 15 letter spaces to the right of fixation for readers of English. Within this total span region, different types of information are acquired with information used to identify a word on the current fixation restricted to about 7 ~ 8 letters to be right of fixation. The span is variable in size and is influenced by factors such as the difficulty of the fixated word and the density of the information. Thus, as mentioned above, the perceptual span is considerably smaller for Chinese than English: for Chinese, the span extends 1 letter to the left of fixation to 3 characters to the right when reading from left-to-right[22]. Finally, the span does not extend below the line that is fixated when reading horizontally arranged text. When reading text that is printed vertically (as can be the case with Chinese and Japanese), readers obviously obtain information in the vertical direction of reading[24].

2. The type of information that is iterated across fixations when reading English is abstract letter information and phonological information[1]. Interestingly, it also appears that phonological codes are used in integrating information across eye movements when reading Chinese[25-27].

3. Where to fixate next in reading seems to be primarily determined by low level features in the

text. For English, the spaces between words serve as effective guideposts for the reader to target the next unidentified word. In Chinese, of course, there are no spaces between the words. Thus, apparently, the eyes are sent to the next unidentified character.

4. When to move the eyes seems to be primarily determined by the ease or difficulty associated with the currently fixated word in English. At the moment, there isn't enough information to determine what causes the eyes to move on when reading Chinese.

5. Certainly, in the case of English and other alphabetic languages, eye movements have proved to be highly useful for studying on-line language processing. Indeed, eye movements represent the gold standard for research on syntactic parsing and ambiguity resolution.

Scene Perception

Scene perception is not as well understood as reading. This is undoubtedly due to the fact that there is a less constrained viewing situation with scenes the reading. Furthermore, the task is not as well-defined as with reading. However, a fair amount has been learned about scene perception by monitoring eye movements. More detailed information about each of the following points can be found in Henderson and Ferreira[28]. Some important findings are as follows.

1. The perceptual span in scene perception is much larger than in reading. More information is acquired during each eye fixation leading to longer fixations and longer saccades than in reading.

2. Interestingly, it appears that not much in the way of visual information survives a saccade. A large literature on change blindness is consistent with this finding[28].

3. Scan paths over a scene tend to be fairly consistent. Thus, when a viewer looks at a scene for a second or third time, the scan path (or order in which objects in the scene are fixated) is fairly similar. However, viewers can, and do, deviate from the original order of scanning when necessary.

4. In formative parts of a scene are invariably fixated. Viewers eyes are quickly drawn to relatively important parts of the scene.

5. The decision of where to fixate next in a scene seems to be very much influenced by salient objects. Viewers tend to move their eyes rather quickly to important parts of the scene. It is unclear what determines when to move the eyes.

Visual Search

There has been a grat deal of research on visual search. However, the vast bulk of it has not involved monitoring eye movements. Recently, Findlay and Gilchrist suggested it is very misguided to do visual search experiments in the absence of knowing what the eyes are doing[29]. Some important pints regarding visual search are:

1. The perceptual span is variable and very much depends on the density of array[30].

2. Viewers tend to look at salient things with respect to what the target is. Distractors which are similar to a given target will draw the eyes to them.

3. Fixations are probably not as tightly linked to cognitive processes in visual search as in reading[31].

What's Next?

In this section, I will provide some personal speculation about where research will go in the next few years with respect to reading, scene perception, and visual search.

Reading

With respect to reading, it seems that there are a number of interesting directions research can take. I anticipate that the following will be the case:

1. Although a lot has been learned about eye movements and reading, I suspect that there will be continued research dealing with the basic perceptual and cognitive processes in reading.

2. As I noted earlier, the fourth era of eye

movement research in reading has been marked by the development of sophisticated models that simulate eye movement behavior in reading. My guess is that further development of the models will continue and that the models will be further refined.

3. The vast majority of research on eye movements and reading involves skilled readers. I think that we will be seeing more and more studies with children at the early stages of reading. The development of more flexible eye-tracking systems will greatly facilitate this effort.

4. We know very little about the characteristics of readers' eye movements as they get older. My guess is that studies of the effect of aging on eye movements will start to appear[32].

5. Surprisingly, very few studies have been done examining the characteristics of eye movements during oral reading. Part of the difficulty here is the technical difficulties associated with coordinating the eye movement record and the speech record. However, recent technological advances have made this a much more manageable situation.

6. Most research on eye movements has involved recording only one eye (though viewing is invariably binocular). We need more and better information on the extent to which the two eyes are coordinated in reading.

7. A relatively small percentage of the research studies dealing with discourse processing have relied on eye movement data. I believe that this trend will change over the next few years and that there will be many more studies on discourse processing using eye movements to get a better sense of moment-to-moment processes.

8. The vast majority of the research on eye movements and reading has been done using alphabetic languages (particularly English). The field is ripe for more cross-cultural studies examining the characteristics of eye movements when reading non-alphabetical writing systems (like Chinese and Japanese).

9. Some studies have recently appeared dealing with music reading[33,34]. I suspect that more of these studies will appear.

10. Some studies have recently appeared in which text and pictures are interspersed[35,36]. Of course, it is typically the case that text and pictures are available for much of the reading we do. More studies of this type will also appear.

Scene Perception

With respect to scene perception, as I noted earlier, I do not think we know as much about the relationship between eye movements and the task as we do about eye movements and reading. I suspect that the following points are appropriate:

1. Researchers need to get a better handle on the perceptual span in scene perception and how it is affected by the scene per se and the specific nature of the task.

2. We need to know more about exactly what determines when the eyes move in scene perception.

3. We need to develop models of scene perception and eye movements that have the type of precision that the models of eye movements during reading have.

4. Experiments need to be done in which scenes are presented in 3D. Recent technological advances have certainly made this possible.

Visual Search

With respect to visual search, my guess is that there will be considerably more research using eye movement paradigms. I suspect that the following points are appropriate:

1. As with scene perception, we need to get a better handle on the perceptual span in visual search.

2. We need to know more about exactly what determines where the eyes move next and when they move in visual search.

3. An interesting question in the field of visual

search is: Does search have a memory? Although many researchers have attempted to answer this question without eye movement data, it seems obvious that recording eye movements should quickly yield answers to this question. Indeed, Klein and MacInnes[37], Peterson, Kramer, Wang, Irwin, and McCarley[38], and McCarley, Wang, Kramer, Irwin, and Peterson[39] have reported eye movement data which show that there is memory during search (so viewers don't go back to previously inspected items all that much). But, more work is needed on this issue.

4. Although there are many sophisticated models of visual search, most of them do not include eye movements. This lack needs to be remedied and complete models of visual search that involve eye movements are needed.

Other tasks

In the foregoing discussion, I have focused on reading, scene perception, and visual search because they are the most frequently studied domains. However, there are a number of other tasks which have been investigated via eye movement recordings. Perhaps the most popular recent area of investigation has involved recording eye movements in listening and speech production tasks. With respect to listening, it has been shown that people look at objects that are mentioned in the current speech stream[40,41]. So, if a person is listening to a story and the objects in the story are pictured in front of them, they tend to look immediately at a given object when it is mentioned. Likewise, in speech production, people look longer at objects that take longer to pronounce or which are less frequent[42]. Studies using this so-called "visual world paradigm" (in which the scene that is being described is presented in front of the viewer and eye movements are recorded) are currently extremely popular. Such studies have been aided by technological advances which make it possible to efficiently record eye movements without fixing the head. This type of research has clearly demonstrated that eye movements are tightly linked to what is available in the scene. However, the assumptions underlying the visual world paradigm haven't been examined as critically as some other areas.

In addition to listening and speech production, eye movements have been examined recently in a number of more dynamic tasks such as (1) looking at print advertisements, (2) driving, (3) action sequences (such as making a sandwich or shooting a basketball), (4) problem solving tasks, (5) looking at Web pages, and (6) virtual reality situations. The foregoing is not intended as an exhaustive list of eye movement applications and there are undoubtedly others that could be listed.

Eye movements will not prove to be informative in every situation. Earlier, I mentioned that many types of memory processes may not be relevant for using eye movement data[43]. But, for many tasks, particularly where knowing something about the temporal sequence of processing is important, eye movements should be quite valuable.

Future Directions

Clearly, there are lots of new applications for eye movement research. In addition, given recent technological advances, many eye trackers are now cheaper and easier to use than earlier versions. However, there are always tradeoffs between the cost of an eye-tracking system, ease of use, and accuracy of the system. When doing the search involved with eye movements one always has to keep these tradeoffs in mind. The ready availability and ease of use of newer eye-tracking systems means that, on the one hand, more researchers will be studying aspects of behavior using eye movements. On the other hand, the ready availability of eye-trackers means that many people who really don't understand eye movements will plug trackers into the wall and start collecting data with them without a good sense of what to do with the resulting data. My own advice to novice eye-trackers is to spend time in a laboratory where the researchers have had a lot of experience with eye-tracking data to get a good sense of how to deal with the data. Although there may be concerns about inappropriate use of eye movement data, in general, the future looks bright for research utilizing eye movement data.

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