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Eye Movements And Reading: What Teachers Need to Know

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From time to time, students in teacher training programs express curiosity about the course work they are required to take in preparation for being credentialed as teachers. Why, for example, some students would like to know, are they being asked to take courses in child development or the psychology of reading? Why not simply take methods courses that focus directly on erasing the achievement gap in reading? In truth, this is an important question that the students are asking because the answer to this question relates directly to how one prepares professionals in disciplines such as medicine, law, and education. Our best colleges of education are in the business of developing professionals. This being the case, what are the most important characteristics of a profession? The answer to this question is that to be considered a professional it is assumed that the practitioner possess a body of theoretical knowledge that can be used to assist in solving the problems encountered in pursuit of that profession. For example, if some students are unmotivated to learn in a classroom setting, is there a body of knowledge that the teacher can use to enhance student engagement with the learning process? Or, if despite the use of efficient reading methods, a student still has continued difficulty learning how to read, does the teacher have the theoretical knowledge necessary to diagnose the problem and resolve it? Highly educated teaching professionals understand the multifaceted nature of motivation and the complex nature of learning disability such that they can help students who are experiencing problems in learning. Of equal importance to theoretical knowledge, it is assumed the professionally trained teacher has mastered the applied skills required to help students achieve the instructional goals of the classroom. In today's educational market place, the demands placed on the teachers have increased enormously and it is becoming increasingly common to expect that every teacher will be able to move students along a skill trajectory that leads to reading proficiency. To meet the increasing demands of the marketplace, teachers need to know more than what methods seem to work. They also need theoretical background knowledge that may prove to be useful as they work with students who are experiencing difficulty learning. For example, they should know how to motivate reluctant readers and they need to know about the work of the eye in reading In addition, if there is a problem that relates to the eyes or to faulty eye movements teachers should be aware of the symptoms so that the problem can be identified and corrected. In essence, course work that students take is designed to help them pursue their work with competency. Consequently this chapter will explain the role of eye movements in reading and it will also explain what teaches can do to help students who are experiencing difficulties with the eye movements that are essential to the reading process.

Discovery of Eye Movements and Eye Physiology

We are all aware that over the course of history, humans have held many misconceptions that science has attempted to correct. For example, in the early 1600s it was commonly thought that the earth was the center of the solar system. When Galileo, the famous physicist and astronomer, tried to correct this error by stating that it was actually the sun that was the center of the solar system, he was tried by the Inquisition, found vehemently guilty of heresy, forced to recant his views, and spent the rest of his life under house arrest. But, that event took place about four centuries ago. One need not go back that far in time to find more recent errors that needed correction. Going back only a little more than one hundred years from now, it was apparent to all observers that the human eyes glanced here and there and everywhere, and it was thought that as the eyes moved across a scene that the eyes were constantly taking in information and constantly feeding this information to the brain.. This same line of reasoning was used in attempting to understand the reading process. It was thought that as the eyes moved across the line of print, that the eyes were constantly taking in information from the page and providing that information to the brain which then analyzed the information for meaning. However, in 1879 Javal, a French scientist, made an important discovery. He found out that the commonly held belief about how the moving eye took in information was incorrect. Contrary to common belief he noted that when reading a text or when viewing a scene out of doors, the eyes did not continuously take in information as they moved across the visual field of the page or the scene out of doors. Instead, he observed that the eyes seemed to jump from spot to spot and at each spot where they jumped there was a pause. He concluded correctly that the eyes took in information only when they paused and not when they were moving. These oculomotor eye movements he called "saccades." Almost twenty years later, Dodge (1900) supported Javal's conclusions by stating, "when the eye movement was unbroken the observer was unable to tell what had been exposed." In fact, before an eye movement occurs, vision is suppressed to prevent the reader from seeing the blur that occurs during a saccade (LaTour, 1962).These oculomotor eye movements that take place while reading fall into three categories:

1. Fixations, when the eye pauses momentarily on a line of print. It is during this pause that the information contained in the eye fixation is taken up and fed to the brain for analysis and meaning. However, it is also possible that during a fixation pause, information from several fixation pauses are interpreted for their meaning.

2. Forward Saccades, Because English is written from left to right, when reading English script the eyes jump from left to right on a line of print. When coming to the end of a line of print, however, the eye movement drops from one line of print down to the next line below. It is important to note that the direction of eye movements when reading depends on what language the text is printed. When reading Hebrew or Arabic script, which is written from right to left, the eye movements are in the opposite direction compared with English.

3. Backward Saccades. Regressions and Re-readings. . Backward eye motions may occur for different reasons. It would be unrealistic to think that the reading process would occur perfectly with excellent comprehension at each point in time. In reality, there are times when comprehension is difficult and re-reading of the text is needed. In re-reading English texts, these eye movements move backward and go from the right to the left. Re-readings typically go backward across several words or more and are for the purpose of improving comprehension. However, not all backward eye movements are for the purpose of enhancing comprehension. Some are made to correct faulty eye movements. Since all eye movements are muscular motions, they are subject to errors. Backward eye movements termed “regressions” occur to correct faulty eye movements that put the focal point in the wrong place. When the focal point is in the wrong place, word recognition is impaired. Generally, regression go backward only about one word or less. Rereading, on

the other hand, allows the eye to reexamine a previously fixated portion of the text. I n re-reading, a student moves quite a few words back to a prior section of a line and then proceeds in a usual manner to re-read from that point forward as a comprehension check.

Instructional implications of eye movements

Eye motions are a natural part of what humans do to observe a scene out of doors or when they read a book. A relatively recent discovery of how the eye processes the information on a printed page indicates that the information is taken in for processing only when the eye pauses during an eye fixation. To process all the information on a page, the eye must move rapidly from point to point to cover the page, and it is only when the eye pauses during an eye fixation that there is an uptake of information that is subsequently fed to the brain where it is analyzed for meaning. Because the reading process does not always proceed smoothly, there are errors that must be corrected. These errors that must be corrected are of two types. One type of error takes place when the reader becomes aware of a comprehension difficulty, in which case there is a backward eye motion called a " re-reading." Re-readings usually go backward encompassing several words. The other type of backward eye motion is termed a "regression" Regressions are used to correct faulty eye motions that place the point of focus in the wrong location, thus impairing word recognition, and the distance the eye moves in a backward direction is usually a word or less.. Faulty eye movements that impair word recognition may occur with experienced as well as beginning readers, but regressions are far more common with beginning readers. Teachers should be aware of the fact that some beginning readers may be experiencing learning to read problems because of faulty eye motions.

As seen in Figure 1, what is remarkable about the eye is that it is similar to a camera. Reduced to its utmost simplicity, in the eye there is the pupil consisting of a hole through which light images from the page of print move. Behind the opening of the pupil there is the lens, and the lens focuses the images from the page toward the back of the eye onto the retina. The retina, located in the back of the eye contains the light sensitive film, and from the retina of the eye the visual information is transported along the optic nerve to the brain.

The major parts of the human eye consist of the cornea, situated in the front of the eye, where it acts like a glass window and allows visual images from the printed page to pass through so they can settle upon the retina. As seen in the figure, the second part called the retina, is located in the back of the eye. It contains cells, some of which are sensitive to letter and word shape. Because the cells in the retina have different purposes, only some of them are capable of identifying letters and words.. And to make matters even more difficult with regard to recognition, the cells that are used for letter and word recognition are found in only a small part of the retina. The problems this poses will be discussed shortly. The third part consists of a collection of communication wires called the optic nerves that carry information from the retina to the brain.

The cornea of the eye contains a hole called the pupil through which visual information from the page passes through on its' way to the retina. Surrounding the pupil is the colored portion called the iris that gives eyes their brown, black, or blue color. The iris also contains muscles that alter the size of the opening of the pupil so that under dim light, the opening of the pupil is larger to admit more light, and under bright light, the opening is smaller to admit less light. Located directly behind the pupil is the lens, and its' purpose is to focus the visual images from the page as sharply as possible upon the retina. The retina, located at the back of the eye contains cells that function like the film in a camera. These retinal cells collect the images and pass them on to the optic nerve, which then sends the visual information to different parts of the brain. Some specialized parts of the brain, in turn, control the oculomotor eye motions that we will discuss shortly.

Different kinds of Cells are found on the retina of the eye

A key idea in this article is that the human eye is not ideally designed for reading, but one of the strategies used for overcoming its shortcomings is through eye motions. The major shortcoming of the eye with regard to reading is that in any eye fixation, only a small part of what is printed on the page is in focus on the retina of the eye. Imagine, for a moment, that you are trying to identify the person who is standing in front of you. As you look at this person, all that is in sharp focus is the person's nose and eyes. The rest is fuzzy but you can detect shape. To identify the person, you rapidly shift your points of focus to other parts so that in time the various parts of the individual's face and body are in sharp focus. The difficulty in determining the identity of this person is somewhat similar to the problem of recognizing words when reading a text. The problem with the eye when reading is that at any given moment only a tiny amount of printed material from a page is in sharp enough focus to enable easy reading. Consequently, rapid eye motions are required to bring different parts of a text onto that tiny area on the retina that can see the letters and words clearly. The area of the retina where the visual image is in sharp focus is known as the fovea. The retina of the eye contains two kinds of cells, rod cells and cone cells. Both kinds are important and have different reading functions. Cone cells provide the visual acuity that enable readers to see letters and words clearly. A major design flaw of the eye so far as reading goes is that the cone cells that enable the reader to see letters most clearly, are not evenly distributed across the retina but are concentrated in a tiny area called the fovea. There are about ten million cone cells packed into the tiny fovea area of each eye where vision is most acute. It is only in this small area of the fovea where the cone cells are packed together that the reader can identify words with the least effort. It is the quality of resolution of the letters that are the first consideration for word identification.

The other cells found in the retina of the eye that contribute to word recognition are the rod cells. These cells are situated outside of the fovea and serve a double function. They are sensitive to word shape and word length. Words that are printed in lower case letters have characteristic shapes, or skylines, and skilled readers automatically use shape as one of the cues for word recognition. In addition to word shape, the other task performed by the rod cells is planning the distance to jump with each left to right forward eye saccade. In planning how far to move, the brain uses word length. Word length is determined by the white space that surrounds each word. At this point we can ask, what is a word? So far as the brain is concerned for the purpose of calibrating what is a word to plan how far to jump, word meaning is not a relevant dimension. All the brain needs to know is that a word is a letter, or group of letters surrounded by space.

Because of the importance of knowing how many letters that fall on the fovea are in sharp focus, we contacted two leaders in the field of eye movement research. Dr. Keith Rayner (personal communication, 5/10/2009) stated, “The number of letters falling in the fovea depends on letter size and viewing angle. In general, 3–4 letters usually occupy 1 degree of visual angle. Since the fovea is about 2 degrees, it would be 6–8 letters in the fovea.” The second expert Dr. George McConkie (personal communication, 5/10 /2009) stated, “The foveal region is the area where we think visibility of letters drops off pretty fast as they move outward from the center of vision . Thus, the problem in answering this question is setting a “clarity” criterion. I suppose that a criterion might be: even the most similar letters can be distinguished at this distance… What Keith and I were after in our original studies was to determine the region within which letter distinctions make a difference. We found this to be about 4 letters to the left and 8 to the right of the directly fixated letter. The greater distance on the right is probably (there is some supportive evidence) an attentional factor rather than retinal resolution differences to left and right." Legge's (2007) research suggests that only six to seven letters surrounding the fixation point on the fovea can be identified with 80% accuracy, and as one moves farther away from the fixation point accuracy of identification drops more. For example, within four letter spaces to the left of the fixation point, or eight letter spaces to the right of the fixation point, accuracy of identification drops to about 60%. In summary, the evidence from the experts is that the size of the window from which letters can be seen with accuracy and clarity falls in a range of six to eight letters. It also appears that the shape of the window is asymmetrical with fewer letters in focus to the left of fixation and more letters in focus to the right of fixation. It is also commonly acknowledged that there is a rapid drop-off of acuity from the point of visual focus that makes word recognition difficult (Feinberg, 1949).

The experts make a good point when they point out that there is no hard and fast rule about the number of letters that are in focus on the fovea because the number of letters in clear focus is a function of letter size and the distance at which they are being viewed. However, there is agreement that the number of letters in focus is not large. McConkie adds there is useful information skilled readers can use that extends beyond the fovea, and that information source comes from the parafoveal region where the rod cells that can detect word shape and length are found. Rayner and Sereno (1994) agree that the parafoveal region surrounding the fovea can provide information that is useful for word recognition and for planning the distance to be moved for the saccadic jumps as the eye moves from point to point. It is the fovea that contains a concentration of cone cells that enables the eye to identify letters with clarity, while the parafoveal region contains the rod cells that are sensitive to word shape and word length information. Information received in the periphery of the eye helps guide the eye to its next eye fixation destination. In essence, the rod cells are part of the eye's guidance system. For skilled readers, word shape provides an additional cue to word recognition. The white spaces surrounding words are important clues as to word boundaries and length. Word length is established by the white space surrounding a word and this information is used by peripheral vision to plan the distance the eye should jump with each saccade.

Instructional Implications

Unfortunately, the human eye is not ideally suited for the task of reading. Because the cone cells of the eye that allow sharp focus of letters and words are packed into such a tiny portion of the retina, the problem of how to make sense of what we look at extends to virtually everything we see, not just reading. Therefore, the strategy of using eye movements to allow an understanding of what one is viewing is used in all that we look at. According to the experts, the number of letters in sharp focus with each eye fixation is approximately 6–8 letters. It is clear to anyone who takes the time to count how many letters are in common English words we encounter when we read, that the range of 6–8 letters in sharp focus would encompass many of the words printed on the page. Regrettably, however, there are also many words that we encounter when we read that are longer than 6 –8 letters. Therefore, readers resort to an eye movement strategy that places all the letters in words in focus. There are a number of clues that readers use in identifying a word. First, there is spelling information from each of the letters used in the word. For example, go<u>ing</u> is legal spelling whereas go<u>nig</u> is not. Second, there is information that comes from word shape when the words are printed in lower case. This knowledge about word shape comes primarily from reading. The adage of "Read more, read better" holds true in this case. In order for the eye to jump the proper distance, the student must know that a word is simply a letter or group of letters surrounded by space. Consequently, the white space surrounding words becomes an important cue that is used by the eye in calibrating how far to jump with each saccade. There are several important questions about the work of the eyes in reading that have not yet been addressed, but they will be discussed shortly. One question pertains to the speed at which the eye fixations occur and the second question relates to how much visual information from each word is processed with each fixation. As we shall see shortly, the number of letters that are processed with each eye fixation is a product of how skilled the reader is and the frequency at which the word is encountered in reading.

The Fixation Pause

Before we embark on a more detailed description of the different eye movements used in reading, we shall describe a robust finding that sheds light on the word recognition process. What is interesting about this finding is that although the study was originally designed to test two competing explanations of how word identification takes place, in time the study led to a new way to conceptualize and measure reading fluency. While most teachers would agree that fluency is one of the holy grails or reading instruction, unfortunately fluency has fallen on hard times because of the difficulties reading scholars have had in agreeing on a definition of fluency and the methods used in assessing it.

The controversy over how words are recognized actually began with Cattell (1947) who presented letters and words to graduate students in Wilhelm Wundt’s lab in Leipzig, Germany. The purpose of the study was to find out what size visual unit was used in word recognition. Was it the single letters in words or was it the entire word? Cattell concluded from his studies that it was the entire word. His findings were used in the United States to resolve the instructional controversy of the day, the spelling method, in which students spelled each word before pronouncing the word or the look-say method in which the students simply said each word without first spelling it. Cattell's report in favor of the whole word resolved the conflict for a while and the look-say method became the method of choice. Years later, Gough (1971) stated in his classic description of the reading process "One second of reading," that the size of the visual unit used in word recognition was the letter, and that each additional letter in a word added about 50 msec. of processing time to the recognition. To test the competing explanations of word recognition we designed a study in which students looked into a computer screen and if the word they saw was an animal word, they had to press a button as quickly as possible and the computer measured response accuracy and how much time it took to recognize the word as an animal word. The words the students saw varied in length from three to five letters. All the 3–5 letter animal words were controlled for word frequency. The logic for the study was simple. If Gough was correct and the unit of word recognition was the letter, then longer words should take longer to recognize and the shorter words should take less time. However, if Cattell was correct and the visual unit used in word recognition was the word, then there should be no difference in processing time based on word length since the unit size was the entire word, and a chunk is a chunk. For this study we used different grade levels, second, fourth, sixth, and college students. All of the students from grade two to college received the same corpus of words. To our surprise, we found that both Cattell and Gough were each correct, but only for a different group of students. The size o f the visual unit used in word recognition by the college students and by the sixth graders was the entire word, so, for these groups, Cattell was correct. For sixth graders and college students long and short words were recognized in the same amount of time. But for the second and fourth graders, the letter was the unit. For these students, the longer words took longer to recognize. Looking at the word recognition process across grade levels, one might conclude that for beginning readers the size of the visual unit used in word recognition was the letter or some unit smaller than the entire word. But as reading skill developed over time and practice, the size of the visual unit increased, so that by sixth grade and college, the unit of recognition was the entire word.

Over several years, modifications and improvements were made in the design of the study that tested what size visual unit is used in word recognition. The shortcoming of the original study was that the body of animal words that were used to test the size of the unit of recognition was very small. We wanted to test not just animal words but all the words in English. To achieve this goal, we changed the task and the instructions were the following: “If the word you see on the computer screen is a real word, press the button as quickly as you can.” We used real words that varied in length from 3–5 letters and all the words were of the same frequency. Even changing the task, we got the same results. Less skilled readers were using letters-units smaller than the whole word - as the unit of recognition while the sixth graders and college students were using the entire word as the unit. This type of study was replicated in Taiwan with students who were reading Chinese words. It is true that the Chinese orthography does not use alphabet letters but their words vary in the number of strokes used to write each word. What was found was that beginning readers in Chinese were reading stroke by stroke. The more strokes in a word, the longer it took to recognize it. But the highly skilled readers were chunking the word as an entire visual unit so that the time to recognize a word was not related to the number of strokes or letters in the word, as they were in the USA.

One might wonder, what is the difference in the process used to recognize words between the second grader and the college student in reading? With some justification one might argue that the college student is a fluent reader while the second grader is not fluent. What exactly can a fluent reader do that the non-fluent reader cannot do? Automaticity theory can be used to answer this question. It states that one is automatic at a skill such as reading if two complex things can be done at the same time. If two skills can be done at the same time, then at least one of them is automatic. The two complex skills that fluent readers can do at the same time with a single eye fixation is decode [word recognition] and comprehend while the non-fluent reader must do each task separately. The beginning reader uses all the cognitive capacity in word recognition and then must switch attention to comprehension, a two step process, and the two steps may require a second eye fixation, while the fluent reader can do both tasks at once. Herein lies a dilemma. How can decoding and comprehension take place at the same time? Surely, decoding must precede comprehension. The dilemma is resolved when one considers the time sequence of what happens during an eye fixation. During a typical eye fixation for a fluent reader that lasts about 300msec. or ⅓ of a second, two things get done in the time span of the fixation, decoding and comprehension as seen in Figure 2 below. However, for the non-fluent reader, during that same 300 msec. time span, only one thing gets done—the decoding or word recognition. Then the non-fluent reader must fixate the word again to comprehend it, a two step process.

As just noted, the typical eye fixation pause lasts for about 300 mesec. or about ⅓ of a second. This pause, however, can be separated into components representing the different processing tasks that must be performed to read with understanding (Abrams and Zubel, 1972). Figure 2 below is a simplified rendition of what takes place during an eye fixation of a skilled reader.

A fluent reader performs essentially five tasks with each fixation pause. The typical pause comes at the end of an eye movement when the eye has just completed a rapid motion from one spot on a text to the next one, somewhat like an automobile that comes to an abrupt stop at a stop sign. In the case of the auto, there is still residual motion that must be halted and stabilized and in the case of the eye, it must be stabilized so that it can focus on the print.

Task One - stabilize. The first job following a saccade is to stabilize the eye.

Task Two - focus. Once the eye is stabilized sufficiently, the next job requirement is to focus the visual images from the page on the retina of the eye where the fovea is located.

Task Three - decode [Convert the word into its sound representation] With the visual image from the page focused on the retina, job three is to engage in word recognition or what many call the decoding process. If the reader is highly skilled and automatic at word recognition, the task is done quickly, accurately, and requires minimal amounts of the cognitive resources and attention. While the typical duration of an eye fixation is .33 seconds, if a person is a skilled reader, the amount of time required for the word recognition process may only require .10 of a second, leaving .23 of a second for comprehension.

Task four - word meaning and comprehension. In fact, the defining characteristic of fluency is the ability to decode and comprehend in the same eye fixation. For skilled fluent readers, the decoding task is done so quickly and it requires so little of the cognitive resources that comprehension can take place at the same time (LaBerge & Samuels, 1974).

Step five- plan next saccade. The final task for the reader is to plan where the next eye movement will be (Abrams & Jones, 1988; Abrams & Zubel, 1972). Since this is a fluent reader, the usual unit of word recognition is the word, which is surrounded by space. Space is a critical cue used by the rod cells in planning the trajectory for the next leap which will probably be the next word.

If, however, the reader is not at the automatic stage of word recognition, there are some important differences in what happens during an eye fixation. First, for non-fluent readers, the word recognition process is usually slower, less accurate, and may use up all of the cognitive resources available at the moment. Thus, during that one eye fixation, for the non-fluent reader the single major accomplishment is word recognition. To add to the complexity of word recognition for the less than fluent reader, the unit of word recognition is smaller than the entire word, leaving the student in the position of having to piece together the letter clusters that in combination make up the word. Since only 6–8 letters that are on the fovea are in sharp focus along with some additional letters that spill off to the right that are not so distinct, the student may resort to selective attention to process the letter cluster. However, once the student has the word, the student's next task is to switch attention to the comprehension process .This constant switching of attention back and forth from decoding to comprehension places a heavy load on short-term memory and makes learning to read so much harder for the less skilled reader than for on the accomplished reader.

Figure 2 is an important visual because it strikes at the heart of the debate on what is reading fluency. This visual shows that skilled readers can within an eye fixation decode and comprehend what is in the text. Unfortunately, beginning readers cannot do both tasks at the same time. They first decode the text and then they switch attention and try to comprehend what they have decoded. The products of the dual process are stored briefly in short-term memory but the decoding-comprehension process must be completed within the ten second duration of that short-term memory system or what was briefly stored will be lost. If the beginning reader loses what was stored, the student simply repeats the process only on the second attempt it is faster having worked through the text previously.

There is supporting evidence from another source showing that for the non-fluent reader, the size of the unit used in word recognition is smaller than the entire word while for the fluent reader the unit used is the word. Taylor (1971) had students from grade one to twelfth grade read one hundred word passages silently for meaning. While the students read, eye cameras recorded the number of eye fixations for the passage. First graders had 224 eye fixations which meant that with each fixation they processed only 0.45 words. The twelfth graders, on the other hand, needed only 96 fixations. Thus, each fixation for the fluent readers encompassed more than a single word.

Instructional implications

One way to define reading fluency is to state that the fluent reader can decode and comprehend during the time span of a single eye fixation. In order for the cognitive resources of the student to be able to do the two tasks during the eye fixation, the decoding task must be automatic. This automaticity of decoding comes about only after a long period of reading practice. Therefore, the student must be motivated to be a reader. Again, read more, read better holds true.

By now it should be abundantly clear that eye movements are essential to overcome the problems created by the fact that the cone cells that can see letters and words clearly are located in only a tiny portion of the retina. To see all the words on the page clearly, the eye must dart about the page in a systematic fashion. Different kinds cells on the retina have different functions. The rod cells are sensitive to word shape and word length. Word length is determined by the white space surrounding each word. In the history of writing, words as we know them today did not exist. It was not until Medieval times that spaces were used to demark words. The space information is used by the eye to plan how far to move the eye with each movement. Thus, with regard to how eye physiology influences reading instruction, it is essential that students know that so far as planning the trajectory of how far the eye should move for a saccade, that a word is defined simply as a letter or group of letters surrounded by space.

Eye fixations in reading are critical because it is during the fixation pause that the eye takes in information from the printed page and begins to process it for meaning. The duration of the typical fixation pause is about 300 msecs [about ⅓ of a second] but pauses can be as short as 100 msec. or as long as 500 msec. [½ second]. It is assumed that during these longer fixation pauses that considerable cognitive processing is going on such as attempting to grasp the meaning of a sentence or integrating information across several sentences. While the term "fixation pause" implies that the eye is motionless this is not actually the case. There is a slight eye tremor the purpose of which is to activate the neurons in the retina so they will continue firing (Gilbert, 1959). Even taking into account the rather brief amount of time it takes to make a forward saccade, in which the eye moves from one fixation pause to the next one, in the space of a single second the eye can make approximately three fixations. The typical person when viewing a scene or a page of printed material seems to be unaware that the information being processed by the brain has been coming in at a rate of three bursts a second and each information burst must be processed rapidly because the visual image coming with each burst survives for less than a second and then it is lost. If, however, the processing is too slow and the visual image disappears from the retina, all is not lost because the reader can re-fixate the original image once again. This tendency to refixate an image that is lost, has led to new scientific terminology. The term "eye fixation pause" represents the time spent on a single fixation, whereas the term "gaze duration" suggests the total amount of time the reader spends on a word across several eye fixations.

Because of the rapid loss of the visual image from a fixated word, or word part, what the reader must do is transform the visual image into its sound representation. For example, when the reader encounters the printed word" c-a-t," it is transformed into its phonological form /c a t/ and then placed in short-term memory. The advantage gained by transferring visual into phonological information and placing the phonological information in short-term memory is that the shelf life of the acoustical information in short-term memory is about ten seconds, which is considerably longer than the duration of visual information which is about one second (Peterson and Peterson, 1959). For the acoustical information that is in short-term memory, ten seconds is usually sufficient time in most cases for skilled readers to complete tasks such as decoding the text, integrating sentence meaning, and finally, moving the information that was temporarily stored in short-term memory into long-term-semantic memory. This need to transform the visual form of words into their phonological representations has led linguists such as Charles Fries (1962) to define reading as a mapping problem where the reader must learn to map the printed word on to it's oral-phonological-auditory representation. According to Fries, once the visual word is transferred into its spoken representation, understanding text is akin to listening to speech in one's head.

Since eye physiology is such that the eye takes in different kinds of information from three different areas - foveal, parafoveal, or peripheral—the total span of information is rather large. Beginning readers had a span of apprehension that was 12 letters to the right and skilled readers had a span of 15 spaces, but one should not assume that words could be recognized that far out, but word length and shape information is obtained (Ikeda & Saida, 1978; Rayner, 1986). Foveal information enables one to identify words, while the parafoveal area provides information of shape and length (Rayner, Well, & Pollatsek, 1986). McConkie and Rayner (1976) have shown that as skill increases the span of recognition increases but not beyond one or two words.

To the person reading a text or viewing a scene outdoors the entire operation appears to be seamless, and it is the seamless nature of the operation that led to the mistaken belief before Javal's time that the eye continuously took in information as it swept across a page of print. In terms of transfer of training, it seems as if several of the eye motion mechanisms used in viewing a scene out of doors are also used in reading a text. For example, regardless of whether one is viewing a scene out-doors or reading a text, virtually no information is taken in during the saccade while the eye is in motion and it is only during the fixation pause that the brain gathers in information for processing. The number of fixation pauses per second for viewing a scene out of doors is about the same as for reading a text (Taylor and Robinson, 1963), and comes to about three fixations per second. Since beginning readers may not be able to recognize a word, or parts of a word that they are focusing on with a single fixation, they may have to refixate the target word more than once to recognize it. With each eye fixation when reading, the number of letters that fall on the fovea that can be seen clearly comes to about 4–5 letters (Feinberg, 1949) a number that easily encompasses the number of letters in a high frequency word. If the reader is skilled and the unit of word recognition is the word, in the space of one second a good reader should be able to process three words per second and in one minute the reader should be able to read at a rate of about 180 words a minute with comprehension, which is a little on the shy side of the figure that Germane and Germane (1922) reported as the silent reading rate for eighth grade good readers.

An important question that eye movement researchers have addressed is does the eye fixate on each word in a text or does the eye skip certain words. It appears that the eye will skip certain words and the words that tend to be skipped are determined, in part, byword length. Short words such as “the,” “a,” and “of” for example tend to be skipped most often because they are not critical to understanding (Brysbaert & Vitu, 1998). Short words, high frequency words, and words that can be predicted from context may be skipped (Paulson and Goodman, 1999).

Gilbert (1959) noted that oral reading is slower than silent reading. This simple fact poses a problem in many classrooms where “round robin” reading is practiced. With the round robin reading system, one student reads orally from a text while the others follow along reading silently from the same text. However, when a poor reader reads orally, with typical slow reading rate and lack of expression, it forces the better readers who are reading silently into twice as many eye fixations and regressions. Gilbert’s concern was that this common round robin reading practice was training poor ocular -motor habits in students. Gilbert cautioned teachers that this common practice should be discontinued, leaving teachers between a rock and a hard place. Of course, teachers had no desire to train poor eye movement habits in students, but having students read orally was how teachers did progress monitoring. If one follows Gilbert’s admonition and discontinues using round robin reading, how can a teacher do progress monitoring without training poor eye movement habits in children? Deno’s (1986) brilliant solution to progress monitoring was to have student’s read orally for one minute and to count the number of correct words read in that brief period of time. By keeping a running record on each student’s reading rate over a period of time, teachers could determine if there was improvement over time as evidenced by consistent improvement in rate up to some asymptote. As good as Deno’s method is, there is a problem, and the problem is that comprehension is not measured, only rate. Despite warnings that meaning should not be sacrificed for the sake of reading rate, some teachers continue this practice. Because of the problems associated with just using reading rate as the yardstick used to measure progress, the time has come for researchers to develop a testing method will focus attention on comprehension as well as reading speed.

During an eye fixation, exactly what part of the word the eye is focused on is important if the reader wants to infer the word using only partial information. Different parts of a word vary in the amount of information they provide the reader. Broerse and Zwaan (1966) found, for example not all parts of a word are equally informative for purposes of word recognition. If a word is separated into its beginning, middle, and end, they found that it is the beginning part that carries the most information for purposes of word recognition. For example, if the reader has already identified the following context "Father was cutting the green ..." and the letter string on the fovea for the next eye fixation contains the following "gr_ _ _" it is an easy task to infer that the next word is "grass." Paulson and Goodman (1999) believe that under certain conditions the reader may skip words in a text and if context is strong enough may use partial information to infer the word. However, as Taylor (1971) states, "Though the average span for a given reader is calculated to be a fraction of a word or one or two words …it is not probable that a reader attempts to apprehend words in fractional parts." However, as Paulson and Goodman (1999) report, there are times when words are inferred and recognized through their parts. In planning an eye movement, the preferred location for a fixation is half way between the beginning and middle of a word (McKonkie, Kerr, Reddex, and Zola, 1988) because given the span of apprehension, and the typical length of common words, the highly informative beginning of a word would be on the fovea.

An important question about the role of eye fixations in reading is how much information is taken in and processed with each fixation pause. The answer is that the eye provides the brain with information from three areas, the foveal area, the parafoveal region and the peripheral region. While all three regions are important, it is the fovea information that is most important because it is here that the letters that fall across the fovea are in sharp focus. The foveal area extends two degrees of visual angle for a maximum of 8 letter space asymmetrically distributed about the point of focus with fewer letters in focus to the left of fixation and more to the right (McConkie & Rayner, 1976), but, as Feinberg (1949) has noted, beyond 4–5 letter spaces from the fixation point, there is a sharp drop-off of clarity. However, for skilled readers the amount of information that is available in a single eye fixation is usually sufficient to permit rapid identification of the word.

Although the parafoveal and peripheral regions do not provide sharp detailed information, nevertheless they provide important information in a number of ways. There is word length information [for example, short words may be skipped]. Word length information is provided by the white space boundaries that skilled readers use in the decoding process. There is also word shape information. Words printed in lower case have a characteristic shape or skyline that aids word recognition In addition, the white space surrounding words is used in planning the trajectory for the next saccade. The division of printed words by spaces is a relatively recent invention that turns out to be a most useful cue to readers. Gaur (1992) writes "The division of words and sentences that we take so much for granted developed only gradually. The majority of ancient scripts …did not divide words and sentences." The reason was that the scribes who wrote the texts were so well versed they did not need any aids as to word boundaries. It was not until about the year 1,200 that monks in preparing medieval manuscripts began to include spaces so that readers who were less skilled could determine where the word boundaries were, and it is this very word boundary information that is used today when the brain plans the next saccade. If the saccadic movement is incorrect and the eye overshoots the target, the flow of meaningful information can be interrupted and the reader may have to self-correct by means of regressive eye movements. To illustrate how difficult reading becomes when word shape and length information are eliminated, try reading the following sentence:

ONLYRECENTLYHAVEEYEMOVEMENTSANDEYEFIXATIONSBEENRECOGNIZEDFO R WHATTHEYREALLYARETHEYAREUSEDINTHEWORDRECOGNITIONPROCESS

Just as the duration of eye fixations vary as a function of reader skill, with skilled readers requiring less time per fixation, so too does the number of eye fixations reflect reader skill. From Taylor's (1971) research we learned that to read a 100 word text, first graders needed 224 eye fixations and twelfth graders needing only 94 fixations. There are yet other factors that should influence eye fixations. For example, how do the goals of the reader influence eye movements? At times the goals may be to study a text carefully to pass an exam, and at other times the reader only desires a casual surface level overview of a text. Surely, we might wonder how will these differences in goals for reading influence visual factors such as duration of eye fixations, span of apprehension, the distribution of attention over the text, the length of a saccade, and regressions?

Regressions and Rereading

To advance through an English text from beginning to end, the direction of eye fixation motion advances from the left to the right. However, there are eye fixations when reading English texts that move in the opposite direction, and go from the right to the left. Fixations following right-to-left eye movements, excluding return sweeps from one line of print to the next, may be considered regressions. Some scholars differentiate between regressions and rereading (Taylor, 1971). Taylor believes that some unnecessary regressions that serve no purpose may reflect poor habits formed during the learning-to-read stage, and these inefficient habits may persist for long periods of time. Other regressions, however, may be purposeful and indicate that the reader has encountered an unanticipated word and is going back to do a comprehension check.

Regression may occur for any number of reasons. For example, in the earliest stages of learning to read, the student must learn how to adjust the accuracy of each eye movement, and at times the trajectory of the forward eye fixation is faulty, requiring a regression to overcome the error. Regressions may also simply reflect poor reading habits that were formed during "round robin" reading when better readers try to follow the oral reading of a less good student. Large numbers of regressions may also reflect the decoding problems of readers who need to return to previous portions of a text to ensure the accuracy of what they have decoded. Or, in the case of skilled readers reading a difficult text, the regressions may reflect what good readers do when they attempt to ensure that they understand the passage they are reading. They return to a previously read portion of the text to do a comprehension check.

Taylor's (1971) research uncovered sizeable differences in the number of regressive eye fixations made as a function of reading skill. In grade one, for example, Taylor found that for every one hundred words read, the student made 52 regressions while the twelfth grade students had only 17 regressive eye movements. How does one account for this large difference in backward eye movements between the unskilled and the skilled readers? The research literature on eye movements suggests two possible reasons for regressions such as poor habits that are acquired in the early grades and are then overcome to some extent with increased skill in the later grades. The second reason for regressions acknowledges the need for comprehension checks which may require regressions. Still another reason to regress may occur when the eye misses its mark during a saccade and the reader tries to adjust by a regressive eye correction. In addition to these reasons for a regression, we are suggesting another possibility. When beginning readers attempt to construct meaning from the text, they engages in a two-step process; first they decode the words and then they attempt to get their meanings. During this two-step process, the decoded words or word parts are moved to short-term memory where they are held for ten seconds before they are lost. Once lost, the reader must start the process over again. Speed is of the essence in this process. We have all noticed during oral reading how beginning readers will laboriously work their way through a sentence, stop, and then regress back to an earlier section of text and start over again. What has happened is the student took too long, got timed out, and what was temporarily stored in short-term memory was lost Therefore, the student had to regress and start over.

By the time students reach college, the number of eye regressions is only 17% per 100 words read, but for first graders it is 52%. Not only do less skilled readers make more backward regressive eye movements but the duration of each eye fixation is longer, which accounts in part for the slower reading speeds of the less skilled readers. Text difficulty also influences eye movements in several ways. Increases in text difficulty are usually accompanied by increases in the duration of the fixation pause, the low frequency unfamiliar words in the text are fixated longer, the distance the eye moves with each saccade decreases, and more regressions occur as more comprehension checks are needed.

Forward saccades

When reading English, forward saccades are characterized by eye movement jumps that move from left to right. During an eye movement, vision is suppressed because the movement is so fast that the brain cannot process the information. The amount of time required to move the eye from fixation to fixation requires only 1/20th of a second. The distance the eye moves in each forward saccade ranges between 1 and 20 letters spaces with the average being 4–5 characters, or the length of a shorter word. It would appear, then, that for skilled readers, for whom the unit of word recognition is the word, the eye jumps from word to word. For skilled readers, what controls the distance the eye jumps with each saccade are the rod cells that are sensitive to the white spaces that mark word boundaries. Ideally, the saccade would place the image of the word so that the letters are spread across the fovea of the eye where letters are in sharpest focus. As we move away from the focal point, clarity of the letters decreases and in less than ten letter spaces out from the point of fixation, visual acuity has dropped by 45%, and ease of word recognition becomes more of a problem (Feinberg, 1949; Legge, et. al,2007). Consequently, as Rayner (1983) states, the planning of how far to move the eye with a forward saccade is critically important.

It is by means of the forward eye movements that the reader is able to advance through a text from its beginning to its end, but as important as the forward eye movements are, they exact a heavy price. And the price is that they slow down reading speed and impair comprehension. It has been shown, for example, when readers look at a point on a computer screen and all the words from a text are presented one at a time to that point, that very high rates of reading accompanied by modest comprehension can be obtained, with rates that range somewhere between 700 to 1000 words per minute. This procedure, however, that requires no eye movements embodies a serious problem. It prevents the reader from making regressions that are essential for comprehension checks (Rayner & Pollatsek, 1989). Rayner and Pollatsek (1989, p. 178) make an important point that advances our understanding of reading fluency. They state that each forward eye movement ends with an eye fixation. During the eye fixation one of the primary goals is to decode the words that are on the fovea of the retina. But they also raise the possibility that during that single eye fixation, more is taking place than only decoding. They raise the possibility that parallel process is taking place such that in addition to word recognition during the eye fixation pause, the reader is also processing meaning. Non fluent readers cannot decode and process meaning at the same time because a significant amount of their cognitive resources are used simply to get the decoding task done (LaBerge & Samuels, 1974).

In summary of this section on eye movements, by means of several kinds of eye movements - forward saccades, regressions, and fixations - readers are able to overcome the limitations presented by the fact that in any given instant the eye can only see with clarity about one short word-or 8 letter spaces - at a time. In the next section we will examine some of the problems that readers experience with eye motions.

Indicators of Eye Problems in Reading

We take the position that oculomotor deficiencies can contribute to reading problems for inexperienced as well as for more experienced readers. Certainly, lack of visual acuity for distance viewing can be picked up through Snellen Eye Charts and corrected through properly fitted glasses but the charts are not useful for detecting problems in close-up viewing as is required in reading. One of the more persistent sources of difficulty in reading is the tracking problem in which readers have difficulty maintaining the focus of the eye on a line of print that is being processed. Some readers with a tracking problem may actually skip entire lines. This problem is not limited to the beginning reader and many experienced readers also share this problem .While loss of place on a line can occur at any location, it is most commonly encountered at the end of a line when the line of print extends across an entire page. The longer the line the more difficult it is to keep one’s place. In fact, the tendency to lose one’s place due to long stretches of text across the page led many newspapers across the country in the 1950s to adopt the practice of using rather narrow columns of text on the newspaper page as a way to reduce tracking problems (Tinker, 1958). A simple way to help beginning readers maintain proper focus on the line of print is to slide a 3 × 5 index card under the line that is being read.

Binocular coordination is essential for efficiency in reading. However, with some individuals, each eye may not always fixate on the same letter during reading. Ideally, each eye should coordinate with the other and both eyes should work as a team. When both eyes are working properly we have binocular coordination. With some individuals, however, the eyes fail to coordinate and the reader must expend considerable effort at reading. Lack of coordination can become so disruptive that the individual closes one eye and reads only from the preferred eye. When there is a lack of binocular coordination, the effort it takes to read may become so great that the individual avoids reading whenever possible. Teachers should look for indicators of lack of binocular coordination. What the teacher should look for are children who seem to be reading from one eye or who avoid reading. Lack of binocular coordination may show up as double images of the words on the page and the visual disturbance leads to increases in the number of eye fixations combined with increases in the duration of the fixation pauses. An excessive number of eye fixations can only be identified with the use of eye motion devices such as the visograph. Adults who have faulty binocular coordination also report that when driving a car, they may see two cars, one to the left and one to the right, when in fact, there is only one automobile. Therefore, they have to figure out which of the car images is the real one and which is the fake one.

A somewhat related eye problem is known as convergence insufficiency. When reading, it is necessary for the eyes to turn inwards toward each other as well as to focus on the letters of the words being read. When the ability of the eyes to converge and focus properly is compromised, it is called convergence insufficiency. If this occurs, the student may report blurred or double vision, headaches when trying to read, burning of the eyes and excessive tearing.

Before leaving this topic of visual problems that may impede reading progress, we want to identify indicators that educators can use to identify readers with possible underlying oculomotor problems that may require professional outside- of -school -intervention, especially if in addition to these symptoms listed below the individual is having difficulty with reading (Taylor & Solan, 1959)

1. Reports visual discomfort.
2. Willing to read only for short periods of time.
3. Eyes burn, fills with tears when reading.
4. Headaches when reading.
5. Frequently looses place on line.
6. Words seem blurred, fuzzy,
7. Difficulty concentrating when reading, desires to escape reading
8. Reports seeing double.
9. Uses finger to keep track on line.
10. Frequently omits words when reading orally
11. One eye drifts or points in a different direction than the other eye.
12. Squints or closes one eye or covers one eye with hand while reading

A Brief Summary

Eye movements are characteristic components of all vision and are an essential component of the reading process. In fact, without eye movements reading could not take place. The physiology of the eye that makes eye movements essential to reading is that the cells of the eye that are sensitive to letter and word identification are located in only a tiny portion of the retina. Thus, the focus of the eye must be moved about to different parts of the page to bring all the words of interest into sharp focus. There are three kinds of oculomotor reading behaviors: eye fixations, forward movements and backward movements. The speed at which these movements occur is so fast that these movements may be easily overlooked. The visual units used in word recognition depend in large measure on the skill of the reader. The units and cues used in word recognition consist of individual letters, digraphs, whole words, word shape and word length. Some beginning reading problems may be linked to faulty eye movements and this article identifies many of the indicators of faulty eye movements. Like all aspects of skill development, practice is essential, and reading must be practiced to get good at it.

References

Abrams, R.A., & Zubel, B.L. (1972). Some temporal characteristics of information processing during reading. *Reading Research Quarterly*, *12*, 41–51.

Broerse, C., & Zwaan, E.J. (1966). Informative value of initial letters in the identification of words. *Journal of Verbal Learning and Verbal Behavior*, *5*, 441–446. doi:10.1016/S0022-5371(66)80058-0

Brysbaert, M., & Vitu, E. (1998). Word skipping: Implications for theories of eye movement control in reading. In Underwood, G. (Ed.), *Eye Guidance in Reading and Scene Perception* (pp. 125–148). Oxford, England: Elsevier. doi:10.1016/B978-008043361-5/50007-9

Cattell, J. (1947). *On the time required for recognizing and naming letters and words, pictures, and colors. James Cattell- Man of Science., Psychological Research*. Lancaster, PA: Science Press.

Dodge, R. (1900). Visual perceptions during eye movements. *Psychological Review*, *V11*, 454–465. doi:10.1037/h0067215

Dodge, R. (1905). The illusion of clear vision during eye movements. *Psychological Bulletin*, *2*, 193–199. doi:10.1037/h0070501

Feinberg, R. (1949). A study of some aspects of peripheral visual acuity. *American Journal of Optometry And American Academy of Optometrics*, *26*, 49–56.

Fries, C. (1962). *Linguistics and Reading*. New York: Holt, Rinehart, and Winston.

Gaur, A. (1992). *The History of Writing*. New York: Cross River Press.

Gilbert, L.C. (1940). Effect on Silent Reading of Attempting to Follow Oral Reading. *The Elementary School Journal*, *40*, 614–621. doi:10.1086/457813

Gilbert, L.C. (1953). Speed of processing visual stimuli and its relation to reading. *Journal of Educational Psychology*, *50*, 8–14. doi:10.1037/h0045592

Gilbert, L.C. (1959). Saccadic movements as a factor in visual perception in reading. *Journal of Educational Psychology*, *50*, 15–19. doi:10.1037/h0040752
Gilbert, L.C. (1959). Saccadic movements as a factor in visual perception in reading. *Journal of Educational Psychology*, *50*, 15–19. doi:10.1037/h0040752
Gough, P.B. (1971). One second of Reading. In J. Kavanaugh and I. Mattingly (Eds.), *Language by Ear and by Eye* (pp. 331–358). Cambridge, MA: MIT Press.

Ikeda, M., & Saida, S. (1978). Span of recognition in reading. *Vision Research*, *18*, 83–88. doi:10.1016/0042-6989(78)90080-9

Javal, L.E. (1879). Essai sur la physiologie de la lecture”. *Annales d'Oculistique*, *82*, 242–253.

Laberge, D., & Samuels, S.J. (1974). Towards a theory of automatic information processing in reading. *Cognitive Psychology*, *6*, 293–323. doi:10.1016/0010-0285(74)90015-2

LaTour, P.L. (1962). Visual threshold during eye movements. *Vision Research*, *2*, 261–262. doi:10.1016/0042-6989(62)90031-7

Legge, G., Sing-Hang, C., Yu, D., Chung, S., Lee, H., & Owens, D. (2007). The case for visual span as a sensory bottleneck. *Journal of Vision (Charlottesville, Va.)*, *7*(2), 1–15. doi:10.1167/7.2.9

McConkie, G., & Rayner, K. (1976). Asymmetry of the perceptual span in reading. *Bulletin of the Psychometric Society*, *8*, 365–368.

Paulson, E., & Goodman, K. (1999). *Eye movements* and miscue analysis: What do the eyes do when a reader makes a miscue? *Southern Arizona Review*, *1*, 55–62.

Peterson, L.R., & Peterson, M.J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology*, *58*, 193–198. doi:10.1037/h0049234

Rayner, K. (1983). *Eye movements in reading*. New York: Academic.

Rayner, K. (1998). Eye Movements in Reading and Information Processing: 20 Years of Research. *Psychological Bulletin*, *124*(3), 372–422. doi:10.1037/0033-2909.124.3.372

Rayner, K., & Pollatsek, A. (1989). *The Psychology of Reading*. Hillsdale, NJ: Erlbaum.

Rayner, K., & Sereno, S.C. (1994). Eye movements in reading: Psycholinguistic studies. In Gernsbacher, M.A. (Ed.), *Handbook of psycholinguistics*. San Diego, CA: Academic Press.

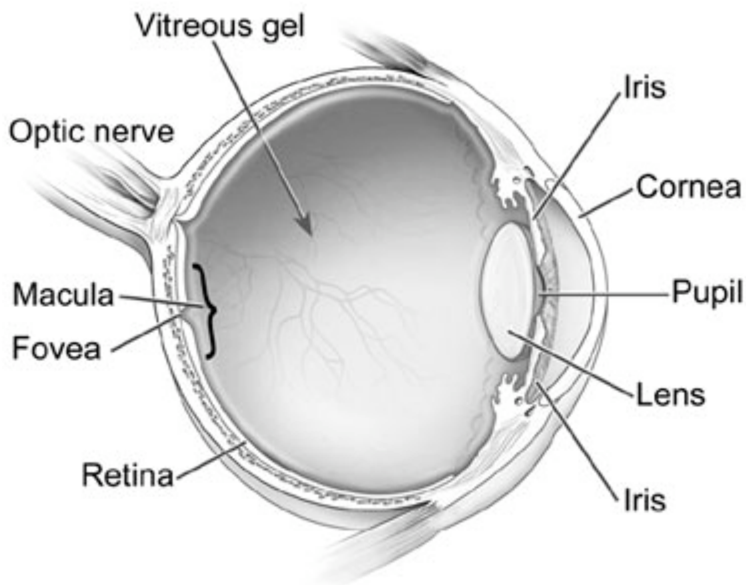
Samuels, S.J., Bremer, C., & LaBerge, D. (1978). Units of word recognition: Evidence for developmental changes. *Journal of Verbal Learning and Verbal Behavior*, *17*, 715–720. doi:10.1016/S0022-5371(78)90433-4

Taylor, S., & Robinson, H. (1963). The relationship of the Ocular-Motor efficiency of the beginning Reader to success in learning to read. *American Educational Research* Conference.

Taylor, S.E. (1971). The dynamic activity of reading: A model of the process. *Research and information bulletin no. 9.*

Tinker, M.A. (1958). Recent studies of eye movements in reading. *Psychological Bulletin*, *55*, 215-223.

Figure 1. The Human Eye



<u>Figure 2.</u> Activities That Take Place During an Eye Fixation by a Fluent Reader

<u>Figure 2.</u> Activities that take place during an eye fixation by a fluent reader.

[←---.10 secs. <u>stabilize</u> and <u>focus</u>--<u>word recognition</u>-decoding→←.23 secs.---<u>comprehension</u> and <u>planning next saccade</u>-→]

[←--------------------------------------300 msec. a single eye fixation, or about 1/3 of as second----------→]