Eye movements during reading, scene perception, visual search, and while looking at print advertisements.

Keith Rayner and Monica S. Castelhano
Department of Psychology
University of Massachusetts, Amherst

Correspondence to:
Keith Rayner
Department of Psychology
University of Massachusetts
Amherst, MA 01003, USA
413-545-2175 (phone); 413-545-0996 (FAX)
rayner@psych.umass.edu

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Abstract

In this chapter, we review research on eye movements in reading, scene perception, and visual search. Understanding eye movements in these three tasks is quite relevant for understanding eye movements when viewers look at print advertisements. Research on issues such as the size of the perceptual span in each task and how decisions are made about when and where to move the eyes in each of the three tasks is discussed. Research on eye movements while looking at ads is also reviewed, and some general comments regarding characteristics of eye movements when looking at ads are provided. We argue that the goal of the viewer has an important influence on the nature of eye movements when looking at ads.

Where do people look in print advertisements? This question has recently generated a fair amount of research activity to determine the factors that influence which aspects of an ad are salient in capturing a viewer's attention (Goldberg, 1999; Pieters, Rosbergen, & Wedel, 1999; Pieters & Warlop, 1999; Pieters & Wedel, 2007; Radach, Lemmer, Vorstius, Heller, & Radach, 2003; Rayner, Miller, & Rotello, 2006; Rayner, Rotello, Stewart, Keir, & Duffy, 2001; Wedel & Pieters, 2000). Given that eye movement research has been so successful in illuminating how cognitive processes are influenced on-line in various information processing tasks like reading, scene perception and visual search (Rayner, 1978, 1998), such interest is not at all surprising. More recently, there have also been attempts to provide models of eye movement control in scanning advertisements (Liechty, Pieters, & Wedel, 2003; Reichle & Nelson, 2003).

Research on eye movements during reading, scene perception, and visual search is obviously quite relevant for understanding how people look at advertisements. Let us be very clear at the outset that our overview of reading will be more complete than our overview of scene perception or visual search. The reason for this is quite obvious. We know more about the nature of eye movements in reading than in the other two tasks. And, the reason for this is also quite apparent. In reading, there is a well-defined task for the viewer: people generally read to understand or comprehend the text. This involves a sequence of eye movements that typically move from left-to-right across the page and then down the page. Of course, the task can be varied somewhat so that, for example, readers are asked to skim the text, and this will result in different eye movements characteristics. Yet, the vast bulk of the research on eye movements during reading has utilized comprehension as the goal of the reader. On the other hand, in scene perception, the nature of the task is inherently much vaguer. Viewers may be asked to look at a scene to remember it, but the sequence in which they examine the scene may be highly idiosyncratic and variable. In visual search, there are many different types of search tasks (search for a letter, search for a colored object, search for a person in a large group picture, search for Waldo in a "Where's Waldo" children's book, and so on), and viewers can use idiosyncratic strategies in dealing with the task. Despite these differences, some information on the nature of eye movements in each task is available. In this chapter, we will review some of the main findings concerning eye movements in these tasks. Then we will move to a brief review of eye movements when looking at print advertisements (see also the chapters by Pieters & Wedel, and by Chandon, Hutchinson, Bradlow, & Young in this volume).

Basic Characteristics of Eye Movements

When we read or look at a scene or search for a target in a visual array, we move our eyes every 250-350 ms. Eye movements serve the function of moving the fovea (the high resolution part of the retina encompassing 2 degrees in the center of vision) on to that part of the visual array that we want to process in detail. Because of acuity limitations in the retina, eye movements are necessary for processing the details of the array. Our ability to discriminate fine detail drops off markedly outside of the fovea in the parafovea (extending out to about 5 degrees on either side of fixation) and in the periphery (everything beyond the parafovea). During the actual eye movement (or saccade), vision is suppressed[1] and new information is acquired only during the fixation (the period of time when the eyes remain still for about 250-350 ms). Although we have the impression that we can process the entire visual array in a single fixation and while we can rapidly obtain the gist of the scene from a single fixation, in reality we would be unable to fully process the information outside of foveal vision if we were unable to move our eyes (Rayner, 1978, 1998).

It is often assumed that we can move our attention so as to attend to one object while the eyes are fixated on another object. While it is indeed the case that in very simple tasks (Posner, 1980) attention and eye location can be separated, in tasks like reading, scene perception, and visual search, covert attention and overt attention (the exact eye location) are pretty tightly linked. To be sure, when looking at a complicated scene, we can dissociate covert and overt attention. But, it generally takes either a certain amount of almost conscious effort to do so (as when we hold fixation and move our attention elsewhere) or it is a natural consequence of programming eye movements. That is, there is considerable evidence that attention typically precedes an eye movement to the intended target of the saccade (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995; Rayner, McConkie, & Ehrlich 1978).

An important point about eye movements is that they are more or less ballistic movements. Once initiated, it is difficult (though not impossible) to change their trajectory. Furthermore, since they are motor movements, it takes time to plan and execute a saccade. In simple reaction time experiments, where there is no necessity of cognitive processing of the fixated material and participants merely need to monitor when a simple fixation target moves from one location to another (and their eyes accordingly), it takes on the order of 175 ms to move the eyes under the best of circumstances (Becker & Jürgens, 1979; McPeek, Skavenski, & Nakayama, 2000; Rayner, Slowiaczek, Clifton, & Bertera, 1983).

Insert Table 1 about here

Table 1 shows some summary information regarding mean fixation durations and saccade lengths in reading, scene perception, and visual search. From this table, it is evident that the nature of the task influences the average amount of time spent on each fixation and the average distance the eyes move. Furthermore, it is very important to note that while the values presented in Table 1 are quite representative of the different tasks, they show a range of average fixation durations and for each of the tasks there is considerable variability both in terms of fixation durations and saccade lengths. To illustrate this, Figure 1 shows the frequency distributions of fixation durations in the three tasks. Here, it is very evident that there is a lot of variability in fixation time measures; although not illustrated here, the same point holds for saccade size measures.

Insert Figure 1 about here

At one time, the combination of the relatively long latency (or reaction time of the eyes) combined with the large variability in the fixation time measures led researchers to believe that the eyes and the mind were not tightly linked during information processing tasks like reading, scene perception, and visual search. Basically, the argument was that if the eye movement latency was so long and if the fixation times were so variable, how could cognitive factors influence fixation times from fixation to fixation? Actually, an underlying assumption was that everything proceeded in a serial fashion and that cognitive processes could not influence anything very late in a fixation, if at all. However, a great deal of recent research has established a fairly tight link between the eye and the mind, and furthermore it is now clear that saccades can be programmed in parallel (Becker & Jürgens, 1979) and that information processing continues in parallel with saccade programming.

With this preamble (and basic information) out of the way, let's now turn to a brief overview of eye movements in each of the three tasks. We'll begin with reading (which will receive the most attention since there is more research on eye movements in this task than the other two), and then move to scene perception and visual search.

Eye Movements in Reading

As noted above, the average fixation duration in reading is about 225-250 ms and the average saccade size is 8-9 character spaces. Typically, character spaces in reading are used rather than visual angle because it has been demonstrated that character spaces drive the eyes more than visual angle. That is, if the size of the print is held constant and the viewing distance varied (so that there are either more or fewer characters per degree of visual angle), how far the eyes move is determined by character spaces and not visual angle (Morrison & Rayner, 1981). The other important characteristic of eye movements during reading is that about 10-15% of the time readers move their eyes back in the text to read previously read material. These regressions, as they are called, are somewhat variable depending on the difficulty of the text. Indeed, fixation duration and saccade size are both modulated by text difficulty: as the text becomes more difficult, fixation durations increase, saccade size decreases, and regressions increase. So, it is very clear that global properties of the text influence eye movements. The three main global measures mentioned here are also influenced by the type of reading material and the reader's goals in reading (Rayner & Pollatsek, 1989).

Likewise, there are also very clear local effects on fixation time on a word (see below). In these studies, rather than using global measures like average fixation duration, more precise processing measures are examined for fixated target words. These measures include: first fixation duration (the duration of the first fixation on a word), single fixation duration (those cases where only a single fixation is made on a word), and gaze duration (the sum of all fixations on a word prior to moving to another word). If it were the case that readers fixated (1) only once on each word and (2) each word, then average fixation duration on a word would be a useful measure. But, the reality is that many words are skipped during reading (i.e., don't receive a direct eye fixation) and some words are fixated more than once. There is good reason to believe that the words that are skipped were processed on the fixation prior to the skip, and likewise there is good reason to think that words are refixated (before moving on in the text) in order to fully process their meaning. The solution to this possible conundrum is to utilize the three measures just described which provide a reasonable estimate of how long it takes to process each word (Rayner, 1998).

The Perceptual Span. A very important issue with respect to reading has to do with the size of the perceptual span (also called the region of effective vision or the functional field of view) during a fixation in reading. Each time the eyes pause (for 200-250 ms) how much information is the reader able to process and use during that fixation? We often have the impression that we can clearly see the entire line of text, even the entire page of text. But, this is an illusion as experiments utilizing a gaze-contingent moving window paradigm (see Figure 2) introduced by McConkie and Rayner (1975; Rayner & Bertera, 1979) have clearly demonstrated.

In these experiments, the rationale is to vary how much information is available to a reader and then determine how large the window of normal text has to be before readers read normally. Conversely, how small can the window be before there is disruption to reading? Thus, in the experiments, within the window area text is normally displayed, but outside of the window, the letters are replaced (with other letters or with X's or a homogenous masking pattern). A great deal of research using this paradigm has demonstrated that readers of English obtain useful information from a region extending 3-4 character spaces to the left of fixation to about 14-15 character spaces to the right of fixation[2]. Indeed, if readers have the fixated word and the word to the right of fixation available on a fixation (and all other letters are replaced with visually similar letters), they are not aware that the words outside of the window are not normal, and their reading speed only decreases by about 10%. If two words to the right of fixation are available within the window, there is no slowdown in reading. Furthermore, readers do not utilize information from the words on the line below the currently fixated line (Rayner, 1998). Finally, in moving mask experiments (Rayner & Bertera, 1979; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981) when a mask moves with the eyes on each fixation covering the letters in the center of vision (see Figure 2), it is very clear that reading is very difficult if not impossible when the central foveal region is masked (and only letters in parafoveal vision are available for reading).

Insert Figure 2 about here

A great deal of other research using another type of gaze-contingent display change paradigm (see Figure 2), called the boundary paradigm (Rayner, 1975), has also revealed that when reader have a valid preview of the word to the right of fixation, they spend less time fixating that word (following a saccade to it) than when they don't have a valid preview (i.e., another word or nonword or random string of letters initially occupied the target word location). The size of this preview benefit is typically on the order of 30-50 ms. Interestingly, research using this technique has revealed that readers don't combine a literal representation of the visual information across saccades, but rather abstract (and phonological) information is combined across eye fixations in reading (McConkie & Zola, 1979; Rayner, McConkie, & Zola, 1980).

Linguistic Influences on Fixation Time. Over the past few years, it has become very clear that the ease or difficulty associated with processing the fixated word strongly influences how long the eyes remain in place. How long the eyes remain in place is influenced by a host of linguistic variables such as the frequency of the fixated word (Inhoff & Rayner, 1986; Rayner & Duffy, 1986), how predictable the fixated word is (Ehrlich & Rayner, 1981; Rayner & Well, 1996), how many meanings the fixated word has (Duffy, Morris, & Rayner, 1988; Sereno, O'Donnell, & Rayner, 2006), when the meaning of the word was acquired (Juhasz & Rayner, 2003, 2006), semantic relations between the word and prior words (Carroll & Slowiaczek, 1986; Morris, 1994), how familiar the word is (Williams & Morris, 2004), and so on (see Rayner, 1998 for review).

Perhaps the most compelling evidence that cognitive processing of the fixated word is driving the eyes through the text comes from experiments in which the fixated word either disappears or is masked after 50-60 ms (Ishida & Ikeda, 1989; Liversedge, Rayner, White, Vergilino-Perez, Findlay, & Kentridge, 2004; Rayner et al., 1981; Rayner, Liversedge, White, & Vergilino-Perez, 2003; Rayner, Liversedge, & White, 2006). Basically, these studies show that if readers are allowed to see the fixated word for 60 ms before it disappears, they read quite normally. Interestingly, if the word to the right of fixation also disappears or is masked, then reading is disrupted (Rayner et al., 2006); this quite strongly demonstrates that the word to the right of fixation is very important in reading. More critically for our present purposes, when the fixated word disappears after 60 ms, how long the eyes remain in place is determined by the frequency of the word that disappeared: if it is a low frequency word, the eyes remain in place longer (Rayner et al., 2003, 2006). Thus, even though the word is no longer there, how long the eyes remain in place is determined by that words' frequency. This is very compelling evidence that the cognitive processing associated with a fixated word is the engine driving the eyes through the text.

To summarize the foregoing overview, it is now clear that readers acquire information from a limited region during a fixation (extending to about 14-15 character spaces to the right of fixation). Information used for word identification is obtained from an even smaller region (extending to about 7-8 character spaces to the right of fixation). Furthermore, the word to the right of fixation is important and readers obtain preview benefit from that word. On some fixations, readers can process the meaning of the fixated word and the word to the right of fixation. In such cases, they will typically skip over the word to the right of fixation. Finally, the ease or difficulty associated with processing the fixated word strongly influences how long readers look at that word.

Models of Eye Movements in Reading. Given the vast amount of information that has been learned about eye movements during reading in the last 25-30 years, a number of models of eye movements in reading have recently appeared. The E-Z Reader model (Pollatsek, Reichle, & Rayner, 2006; Rayner, Ashby, Pollatsek, & Reichle, 2004;

Rayner, Reichle, & Pollatsek, 1998; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Pollatsek, & Rayner, 2006; Reichle, Rayner, & Pollatsek, 2003) is typically regarded as the most influential of these models. In the interests of space limitations, other models will not be discussed here[3]. Basically, the E-Z Reader model accounts for all of the data and results discussed above, and it also does a good job of predicting how long readers will look at words, which words they will skip, and which words will be refixated. It can account for global aspects of eye movements in reading, while also dealing with more local processing characteristics; the competitor models also can account for similar amounts of data. In many ways, the models share many similarities, though they differ on some precise details and how they go about explaining certain effects varies between them. As a computational model, E-Z Reader has the virtue of being highly transparent, so it makes very clear predictions and when it can't account for certain data, it is very clear why it can't (thus enabling one to change parameter values in the model). The model has also enabled us to account for data patterns that in the past may have been difficult to explain. The model isn't perfect and has many limitations. For example, higher order processes due to sentence parsing and discourse variables do not currently have an influence within the model. It basically assumes that lexical processing is driving the eyes through the text, but we believe that this isn't an unreasonable assumption[4].

The main, and concluding, point from the foregoing is that great advances have been made in understanding eye movements in reading (and inferring the mental processes associated with reading) via careful experimentation and via the implementation of computational models that nicely simulate eye movements during reading. In the next two sections, eye movements during scene perception and visual search will be discussed. Although there hasn't been as much research on these areas as on reading, it is still the case that some clear conclusions emerge from the work that has been done.

Eye Movements and Scene Perception

Figure 3 shows the eye movements of a viewer on a scene. As is very evident in this figure, viewers don't fixate on every part of the scene. This is largely because information can be obtained over a wider region in scene perception than reading. However, it is clear that the important aspects of the scene are typically fixated (and generally looked at for longer periods than less important parts of the scene). In Figure 3, the fixations are on the informative parts of the scene, and viewers do not fixate on the sky or the road in front of the houses. As we noted at the outset, the average fixation in scene perception tends to be longer than that in reading, and likewise the average saccade size tends to be longer. In this section, a brief summary of where people tend to look in scenes will be provided, as well as information regarding the perceptual span region for scenes and the nature of eye movement control when looking at scenes.

Insert Figure 3 about here

Getting the Gist of a Scene. One very important general finding with respect to scene perception is that viewers get the gist of a scene very early in the process of looking, sometimes even from a single brief exposure that is so quick that it would be impossible to move the eyes (De Graef, 2005). In fact, in a recent study, Castelhano and Henderson (2006b) showed that with exposures lasting as little as 40 ms, participants were able to extract enough information to get the gist of the scene. It has typically been argued that the gist of the scene is obtained in the first fixation, and that the remaining fixations on a scene are used to fill in the details.

Where do Viewers Look in Scenes? Since the pioneering work of Buswell (1938) and Yarbus (1967), it has been widely recognized that viewer's eyes are drawn to important aspects of the visual scene and that their goals in looking at the scene very much influence their eye movements. Quite a bit of early research demonstrated that the eyes are quickly drawn to informative areas in a scene (Antes, 1974; Mackworth & Morandi, 1967) and that the eyes quickly move to an object that is out-of-place in a scene (Friedman, 1979; Loftus & Mackworth, 1978). On the other hand, the out-of-place objects in these scenes tended to differ from the appropriate objects on a number of dimensions (Rayner & Pollatsek, 1992). For example, an octopus in a farm scene is not only semantically out-of-place, but it also tends to have more rounded features than the objects typically in a farm scene. So, these early studies confounded visual saliency and semantic saliency. More recent experiments in which appropriate featural information was well-controlled raise questions about the earlier findings, and suggest that the eyes are not invariably and immediately drawn to out-of-place objects (De Graef, Christiaens, & d'Ydewalle, 1990; Henderson, Weeks, & Hollingworth, 1999).

But, it is certainly the case that the eyes do get quickly to the important parts of a scene. In a recent study, the influence that context has on the placement of eye movements in search of certain objects within pseudo-realistic scenes was investigated (Neider & Zelinksy, 2006). Viewers were asked to look for target objects that are typically constrained to certain parts of the scene (i.e., jeep on the ground, blimp in the sky). When a target was present, fixations were largely limited to the area one would expect to find the target object (i.e., ground or sky); while, when the target was absent, the inclination to restrict search to these areas was less so. They also found that when the target was in the expected area, search times were on average 19% faster. From these results, they concluded that not only do viewers focus their fixations in areas of a scene that most likely contain the target to improve search times, but also that the visual system is flexible in the application of these restriction and viewers very quickly adopt a "look everywhere" strategy when the first proves unfruitful. Thus, it seems that search strategies in scenes are guided by the scene context, but not with strict adherence.

It is also clear that the saliency of different parts of the scene influence what part of the scene is fixated (Parkhurst & Niebur, 2003; Mannan, Ruddock, & Wooding, 1995, 1996). Saliency is typically defined in terms of low-level components of the scene (such as contrast, color, intensity, brightness, spatial frequency, etc.). Indeed, there are now a fair number of computational models (Baddeley & Tatler, 2006; Itti & Koch, 2000, 2001; Parkhurst, Law, & Niebur, 2002) that use the concept of a saliency map to model eye fixation locations in scenes. In this approach, bottom-up properties in a scene (the saliency map) make explicit the locations of the most visually prominent regions of the scene. The models are basically used to derive predictions about the distribution of fixations on a given scene.

While these models can account for some of the variability in where viewers fixate in a scene, they are limited in that the assumption is that fixation locations are driven primarily by bottom-up factors and it is clear that higher level factors also come into play in determining where to look next in a scene (Henderson & Castelhano, 2006a; Henderson & Ferreira, 2004). A model that includes more in the way of top-down and cognitive strategies has recently been presented by Torralba, Oliva, Castelhano, and Henderson (2006). Indeed, while there has been a considerable amount of research to localize *where* viewers move their eyes while looking at scenes, there has been precious little in the way of attempting to determine what controls *when* the eyes move. This is in contrast with reading where the issues of *where* to move the eyes and *when* to move the eyes have both received considerable attention. One recent study attempting to correct this imbalance investigated the effect of repeated exposure to a scene and its effect on fixation durations (Hidalgo-Sotelo, Oliva & Torralba, 2005). Observers were asked to search for a target and respond whether it was present in a scene while their eye movements were tracked. Unbeknownst to them, there were certain scene-target combinations that repeated throughout the experiment twenty times. As expected, these repeated searches showed a large decrease in response time. Interestingly though, the number of fixations did not decrease as much as the average fixation duration prior to fixating the target object. Furthermore, the results showed that the proportion of target objects that were fixated before a response was made did not change with increased repetitions (85%). And although the average gaze durations on the target fell from 450 ms during the first exposure to 310 ms in the twentieth, it seems that observers chose to verify the target object before making a response. These results showed that with repeated exposure, the reduced response time is primarily due to a decrease in the average duration of fixations during the search and in the time to verify the target object. Thus, it seems that in this study it became easier to identify the fixated regions as non-targets and targets, but not to cut down on the number of fixations made.

Another difference between scenes and reading is the question of what information is used from memory. We know that memory for the information read plays a large role in integrating information from the current fixation with what has already been read and directing subsequent fixations (such as deciding whether to regress and reread a certain section). In scenes, the role that memory plays in directing fixations is not as clear. Many of the models using saliency as the primary driving force of eye movements do not consider how information gathered initially may influence the placing of subsequent fixations. In a recent study, Castelhano and Henderson (2006a) investigated whether this initial representation of a scene can be used to guide subsequent eye movements on a real-world scene. Observers were shown a very short preview of the search scene and then were asked to find the target object using a moving window, thus eliminating any immediately available visual information. A preview of the search scene itself elicited the most efficient searches when compared to a meaningless control (the preview yielded fewer fixations and the shortest saccade path to the target). When a preview of another scene within the same semantic category was shown (thereby providing general semantic information without the same visual details), results revealed no improvement in search. These results suggest that the initial representation used to improve search efficiency was not based on general semantics, but rather on something more specific. When a reduced scale of the search scene was shown as the preview, search efficiency measures were as high as when the full-scale preview was shown. Taken together, these results suggest that the initial scene representation is based on abstract, visual information that is useful across changes in spatial scales. Thus, the information used to guide eye movements in scenes is said to have two sources: the saliency of the scene and the information in memory about that scene and scene type.

The Perceptual Span. How much information do viewers obtain in a scene? As noted at the outset of this section, it is clear that information is acquired over a wider range of the visual field when looking at a scene than is the case for reading. Henderson, McClure, Pierce, and Shrock (1997) used a moving mask procedure (to cover the part of the scene around the fixation point) and found that although the presence of a foveal mask influenced looking time, it did not have nearly as serious effects for object identification as a foveal mask has for reading.

Nelson and Loftus (1980) examined how close to fixation an object had to be for it to be recognized as having been in the scene. They found that objects located within about 2.6 degrees from fixation were generally recognized, but recognition depended to some extent on the characteristics of the object. They also suggested that qualitatively different information is acquired from the region 1.5 degrees around fixation than from regions further away (see also Nodine, Carmody, & Herman, 1979). While a study by Parker (1978) is often taken to suggest (see Henderson & Ferreira, 2004 for discussion) that the functional field of view for specific objects in a scene is quite large (with a radius of at least 10 degrees around fixation resulting in a perceptual span of up to 20 degrees), other more recent studies using better controlled stimuli and more natural images (Henderson & Hollingworth, 1999; Henderson, Williams, Castelhano, & Falk, 2003) suggest that the functional field of view extends about 4 degrees away from fixation.

An early study using the moving window technique by Saida and Ikeda (1979) suggested that the functional field of view is quite large, and can consist of about half of the total scene regardless of the absolute size of the scene (at least for scenes that are up to 14.4 degrees by 18.8 degrees). In this study and other studies using the moving window paradigm (van Diepen & d'Ydewalle, 2003; van Diepen, Wampers, & d'Ydewalle, 1998) normal scene information within the window area around a fixation point is presented normally, but the information outside of the window is degraded in some systematic way. Saida and Ikeda (1979) found a serious deterioration in recognition of a scene when the window was limited to a small area (about 3.3 degrees X 3.3 degrees) on each fixation. Performance gradually improved as the window size became larger, as noted, up to about 50% of the entire scene. Saida and Ikeda noted that there was considerable overlap of information across fixations.

It should be clear from the studies we have reviewed that the answer to the question of how large the perceptual span in scene perception is hasn't been answered as conclusively as it has in reading. Nevertheless, it does appear that viewers typically gain useful information from a fairly wide region of the scene, which also probably varies as a function of the scene and the task of the viewer. For instance, the ease with which an object is identified has been linked to its orientation (Boutsen, Lamberts, & Verfaille, 1998), frequency within a scene context (Hollingworth & Henderson, 1998), and how well camouflaged it is (De Graef, et al., 1990). As has been shown in reading (Henderson & Ferreira, 1990), it is likely that the ease of identifying a fixated object has an effect on the extent of processing in the periphery.

Preview Benefit. Just as in reading, viewers obtain preview benefit from objects that they have not yet fixated (Henderson, 1992; Henderson, Pollatsek, & Rayner, 1987, 1989; Pollatsek, Rayner, & Collins, 1984; Pollatsek, Rayner, & Henderson, 1990) and the amount of the preview benefit is on the order of 100 ms (so it is larger than in reading). Interestingly, viewers are rather immune to changes in the scene. In a series of experiments by McConkie and Grimes (McConkie, 1991; McConkie & Grimes, 1995; Grimes, 1996) observers were asked to view scenes with the task of memorizing what they saw. They were also informed that changes could be made to the image while they were examining it, and they were instructed to press a button if they detected those changes. While observers viewed the scenes, changes were made during a saccade. As discussed earlier, during saccades vision is suppressed meaning that these changes would not have been visible as they were occurring. Remarkably, observers were unaware of most changes, which included the appearance and disappearance of large objects and the changing of colors, all of which were happening while the scene was being viewed. Although later studies found that any disruption served to induce an inability to detect changes (such as inserting a blank screen in between two changing images (Rensink, Clark & O'Regan, 1997), movie cuts (Levin & Simons, 1997), or the simultaneous onset of patches covering portions of the scene (O'Regan, Rensink, & Clark, 1999), these experiments highlighted the relation between what is viewed during the initial exploration of a scene and then what is remembered about that scene. Further studies have shown that this lack of awareness does not mean that there is no recollection of any visual details, but rather that the likelihood of remembering visual information is highly dependent on the processing of that information (Hollingworth & Henderson, 2002; Hollingworth, 2003). This means that knowing something about the processes that go on during a fixation on a scene is extremely important if one would want to predict how well visual information being viewed is stored.

When do viewers move their eyes when looking at scenes? With the assumption that attention precedes an eye movement to a new location within a scene (Henderson, 1992; van Diepen & D'Ydewalle, 2003), it follows that the eyes will move once information at the center of vision has been processed and a new fixation location has been chosen. In a recent study, van Diepen and D'Ydewalle (2003) investigated when this shift in attention (from the center of fixation to the periphery) took place in the course of a fixation. They had observers view scenes whose information at the center of fixation was masked during the initial part of fixations (from 20- 90 ms). In another case, the periphery was masked at the beginning of each fixation (for 10-85 ms). As expected based on the assumptions made above, they found that when the center of fixation was masked initially, fixation durations increased with longer mask durations (61% increase). When the periphery was masked, they found a slight increase in fixation durations, but not as much as with a central mask (15% increase). Interestingly, they found that the average distance of saccades decreased and the number of fixations increased with longer mask durations in the periphery. They surmised that with the longer peripheral masking durations the visual system does not wait for the unmasking of peripheral information, but instead chooses information that is immediately available. These results suggest that the extracting of information at the fovea occurs very rapidly, and the attention is directed to the periphery almost immediately following the extraction of information (70-120 ms) to choose a viable saccade target. Although the general timing of the switch between central and peripheral information processing is now being investigated, the variability of information across scenes makes it more difficult to come up with a specific time frame as has been done in reading.

Eye Movements and Visual Search

Visual search is a research area that has received considerable effort over the past 40 years. Unfortunately, the vast majority of this research has been done in the absence of considering eye movements (Findlay & Gilchrist, 1998). That is, eye movements have typically not been monitored in this research area and it has often been assumed that eye movements are not particularly important in understanding search. However, this attitude seems to be largely changing as there are now many experiments reported each year on visual search utilizing eye movements to understand the process. Many of these studies deal with very low-level aspects of search and often focus on using the search task to uncover properties of the saccadic eye movement system (see Findlay, 2004; Findlay & Gilchrist, 2003).

In this chapter, we'll focus primarily on research that has some implications for how viewers search through arrays to find specific targets (as is often the case when looking at ads). As we noted at the outset, fixation durations in search tend to be highly variable. Some studies report average fixation times as short as 180 ms while others report averages on the order of 275 ms. This wide variability is undoubtedly due to the fact that how difficult the search array is (or how dense or cluttered it is) and the exact nature of the search task strongly influence how long viewers pause on average. Typically, saccade size is a bit larger than in reading (though saccades can be quite short with very dense arrays) and a bit shorter than in scene perception.

The Search Array Matters. Perhaps the most obvious thing about visual search is that the search array makes a big difference in how easy it is to find a target. When the array is very dense (with many objects and distractors) or cluttered, search is more costly than when the array is simple or less dense and eye movements typically reflect this fact (Bertera & Rayner, 2000; Greene & Rayner, 2001a. 2001b). The number of fixations and fixation duration both increase as the array becomes more complicated, and the average saccade size decreases (Vlaskamp & Hooge, 2006). Additionally, the configuration of the search array has an effect on the pattern of eye movements. In an array of objects arranged in an arc, fixations tend to fall in-between objects, progressively getting closer to the area where viewers think the target is located (Zelinsky, 2005; Zelinsky, Rao, Hayhoe, & Ballard, 1997). On the other hand, in randomly placed arrays, other factors such as color of the items and shape similarity to the target object influence the placement of fixations (Williams, Henderson, & Zacks, 2005).

Does Visual Search Have a Memory? This question has provoked a considerable amount of research. Horowitz and Wolfe (1998) initially proposed that visual search doesn’t have a good memory and that the same item will be re-sampled during the search process. However, they made this assertion based on reaction time functions, and eye movement data are ideal for addressing the issue (since one can examine how frequently the eyes return to a previously sampled part of the array). And, eye movement experiments (Beck, Peterson, Boot, Vomela, & Kramer, 2006; Beck, Peterson, & Vomela, 2006; Peterson, Kramer, Wang, Irwin, & McCarley, 2001) make it quite clear that viewers generally do not return to previously searched items.

The Perceptual Span. Rayner and Fisher (1987a, 1987b) used the moving window technique as viewers searched through horizontally arranged letter strings for a specified target letter. They found that the size of the perceptual span varied as a function of the difficulty of the distractor letter; when the distractor letters where visually similar to the target letter, the size of the perceptual span was smaller than when the distractor letters were distinctly different from the target letter. They suggested that there were two qualitatively different regions within the span: a decision region (where information about the presence or absence of a target is available, and a preview region where some letter information is available but where information on the absence of a target is not available.

Bertera and Rayner (2000) had viewers search though a randomly arranged array of letters and digits for the presence of a target letter. They used both the moving window and moving mask techniques. They varied the size of the array (so that it was 13 degrees by 10 degrees, 6 degrees by 6 degrees, or 5 degrees by 3.5 degrees), but the number of items was held constant (so in the smaller arrays, the information was more densely packed). The moving mask had a deleterious effect on search time and accuracy, and the larger the mask, the longer the search time. In the moving window condition, search performance reached asymptote when the window was 5 degrees (all letters/digits falling within 2.5 degrees from the fixation point where visible with such a window size while all other letters were masked).

Where and When to Move the Eyes. While there have been considerable efforts undertaken to determine the factors involved in deciding where and when to move the eyes (Greene, 2006; Greene & Rayner, 2001a, 2001b; Hooge & Erkelens, 1996, 1998; Jacobs, 1986; Vaughan, 1982), a clear answer to the issue has not emerged. Some have concluded that fixation durations in search are the result of both preprogrammed saccades and fixations that are influenced by the fixated information (Vaughan, 1982). Others have suggested that the completion of foveal analysis is not necessarily the trigger for an eye movement (Hooge & Erkelens, 1996, 1998) while others have suggested that it is (Greene & Rayner, 2001b). Rayner (1995) suggested that the trigger to move the eyes in a search task is something like: is the target present in the decision area of the perceptual span? If it is not, a new saccade is programmed to move the eyes to a location that has not been examined. As with reading (and presumably scene perception), attention would move to the region targeted for the next saccade.

Finally, the decision about where to fixate next and when to move the eyes is undoubtedly strongly influenced by the characteristics of the specific search task and the density of the visual array. In a recent study, van Zoest, Donk, and Theeuwes (2004) investigated what type of information had more influence over the placement of fixations: goal-driven information (i.e., target knowledge) or distractor saliency. They found that when fixations were made quickly subjects tended to fixate the target and distractor equally, however for longer fixation latencies, the target was fixated more often. They concluded that the longer observers took to choose a location and execute a saccade, the more likely it would be influenced by goal-driven control. Thus it seems that the parallels between visual search arrays and scenes are greater than with reading, in that visual saliency plays a greater role in directing fixations. Also, search for targets within visual search displays and scenes have different dimensions that are not as variable as in reading. For instance, with respect to search tasks, there are many different types of targets that people may be asked to search for. Searching for a certain product in a grocery store shelf or searching for a particular person in a large group picture or for a word in a dictionary may well yield very different strategies than skimming text for a word (and hence influence eye movements in different ways). Although the task is generally much better defined in visual search than in scene perception, it cannot be as well specified as in reading.

General Comments on Eye Movements

In the preceding sections, we have reviewed research on eye movements in three tasks that are very much related to what happens when viewers look at print advertisements. Although there are obviously many differences between reading, scene perception, and visual search, there are some general principles that we suspect hold across the three tasks (and are relevant for considering eye movements when looking at ads). First, how much information is processed on any fixation (the perceptual span or functional field of view) varies as a function of the task. The perceptual span is obviously smaller in reading than in scene perception and visual search. Thus, for example, fixations in scene perception tend to be longer and saccades are longer because more information is being processed on a fixation. Second, the difficulty of the stimulus influences eye movements: in reading, when the text becomes more difficult, eye fixations get longer and saccades get shorter; likewise in scene perception and visual search, when the array is more difficult (crowded, cluttered, dense), fixations get longer and saccades get shorter. Fourth, the difficulty of the specific task (reading for comprehension versus reading for gist, searching for a person in a scene versus looking at the scene for a memory test, and so on) clearly influences eye movements across the three tasks. Finally, in all three tasks there is some evidence (Najemnik & Geisler, 2005; Rayner, 1998) that viewers integrate information poorly across fixations and that what is most critical is that there is efficient processing of information on each fixation.

Eye Movements and Advertisements

In comparison to reading, scene perception, and visual search, there has been considerably less research on eye movements when looking at ads than there has been on these other topics. Obviously, however, what is known about eye movements in these other tasks has some relevance to looking at ads since there is often a reading component, a scene perception component, and a search component to the task of looking at an ad.

While there was some research on eye movements while viewers examined print advertisements prior to the late-1990's (see Radach et al., 2003, for a summary), it tended to be rather descriptive and non-diagnostic. More recent research has focused on attempts to analytically determine how (1) aspects of the ad and (2) the goal of the viewer interact to influence looking behavior and the amount of attention devoted to different parts of the ad. For example, Rayner et al. (2001) asked American participants to imagine that they had just moved to the United Kingdom and that they needed to either buy a new car (the car condition) or skin care products (the skin care condition). Both groups of participants saw the same set of 24 ads; participants in the car group saw 8 critical car ads, but they also saw 8 critical skin car ads and 8 filler ads (consisting of a variety of ad types) while participants in the skin care group also saw the same 8 car ads, the same 8 skin care ads, and the same 8 filler ads. Obviously, the two different types of ads should have differing amounts of relevance to the viewers. Indeed, viewers in the car condition spent much more time looking at car ads than at skin care ads, while viewers in the skin care condition spent much more time looking at skin care ads than car ads.

In a follow-up experiment, Rayner et al. (2006) used the same set of ads, but this time participants were asked to rate the ads in terms of (1) how effective each ad was or (2) how much they liked the ad. Interestingly, the pattern of looking times was very different in this experiment in comparison to the earlier Rayner et al. (2001) study. Indeed, when asked to rate pictures for effectiveness or likeability, viewers tended to spend much more time looking at the picture part of the ad in comparison to the text. In contrast, viewers in the Rayner et al. (2001) study spent much more time reading the text portion of the ad, particularly if the ad was relevant for their goal. Thus, viewers in the car condition spent a lot of time reading the text in the car ads (but not in the skin care ads), while those in the skin care condition spent a lot of time reading the text in the skin care ads (but not in the car ads). As seen in Table 2, the amount of time that viewers devoted to the picture or text part of the ad varied rather dramatically as a function of their goals. When the goal was to think about actually buying a product they spent more time reading; when the goal was to rate the ad, they spent much more time looking at the picture (for further evidence of the importance of the viewer's goals, see Pieters & Wedel, 2007).

Insert Table 2 about here

Clearly, advertisements differ in many ways, yet from our perspective there appear to be some underlying principles with respect to how viewers inspect them. First, when viewers look at an ad with the expectation that they might want to buy a product, they often quickly move their eyes to the text in the ad (Rayner et al., 2001), especially the large text (typically called the headline). Second, viewers spend more time on implicit ads in which the pictures and text are not directly related to the product than they spend on explicit ads (Radach et al., 2003). Third, although brand names tend to take up little space in an ad, they receive more eye fixations per unit of surface than text or pictures (Wedel & Pieters, 2000). Fourth, viewers tend to spend more time looking at the text portion than at the picture portion of the ad, especially when the amount of space taken up is taken into account (Rayner et al., 2001; Wedel & Pieters, 2000). Fifth, viewers typically do not alternate fixations between the text and the picture part of the ad (Rayner et al., 2001, 2006). That is, given that the eyes are in either the text or picture part of the ad, the probability that the next fixation is also in that part of the ad is fairly high (about .75, Rayner et al., 2006). Rayner et al. (2001) found that viewers tended to read the headline or large print, then the smaller print, and then they looked at the picture (although some viewers did an initial cursory scan of the picture). However, Radach et al. (2003) found that their viewers looked back and forth between different elements (often scanning back and forth between the headline, the text, and the picture). Radach et al. (2003) argued that the differences lie in the fact that the tasks they used were more demanding than those used by Rayner et al. (2001). This brings us to the sixth important point: it is very clear that the goal of the viewer very much influences the pattern of eye movements and how much time viewers spend on different parts of the ad (Pieters & Wedel, 2007; Rayner et al., 2006). As noted above (see Table 2), where people look (and how soon they look at the text or the picture part of the ad) varies rather dramatically as a function of the goals of the viewer (Rayner et al., 2006).

Summary

In this chapter, we have reviewed the basic findings concerning eye movements when (1) reading, (2) looking at a scene, (3) searching through a visual array, and (4) looking at ads. Although there is no question that the tasks differ considerably, and that eye movements also differ considerably as a function of the task, it is the case that eye movements can be very informative about what exactly viewers do in each type of task.

Each of these points has been discussed in the preceding sections. We didn't discuss how people look at ads on web pages (or eye movements on web pages in general) since such research is in its infancy. But, we do suspect that many of the findings we have outlined above with more traditional tasks will carry over to that situation. It will also be interesting to see how well the findings we have described hold up when viewers look at dynamically changing scenes (as virtually all of the work that we described has dealt with static scenes). Finally, our expectation is that eye movements will continue to play a valuable role for those interested in how ads are processed and how effective they are for consumers.

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Footnotes

1. Although vision is suppressed, for most cognitive tasks, mental processing continues during the saccade (see Irwin, 2004 for a review of when cognition is also suppressed during saccades).

2. The nature of the writing system also very much influences the size of the perceptual span, but this is beyond the scope of the present chapter (see Rayner, 1998 for a review).

3. For a comprehensive overview of these models, see the 2006, vol. 7 special issue of *Cognitive Systems Research.*

4. Our primary argument is that lexical processing drives the eyes through the text and higher order processes primarily serve to intervene when something doesn’t compute (see Rayner, Warren, Juhasz, & Liversedge, 2004).

Table 1. Eye movement characteristics in reading, scene perception, and visual search.

Task	Mean Fixation Duration (ms)	Mean Saccade Size (degrees)
Silent reading	225-250	2 (8-9 letter spaces)
Oral reading	275-325	1.5 (6-7 letter spaces)
Scene perception	260-330	4
Visual search	180-275	3

Table 2. Mean viewing time (in seconds) and number of fixations for the text and picture parts of ads as a function of task. Values in parentheses equal the percent of time looked at the text or picture (for the Viewing Time) and the percent of fixations in the text or picture (for the Number of fixations).

	Viewing Time		Number of Fixations	
	Text	Picture	Text	Picture
Rayner et al. (2006)	3.64 (39%)	5.72 (61%)	14.7 (39%)	22.7 (61%)
Rayner et al. (2001)				
Intended	5.61 (73%)	2.12 (27%)	25.2 (72%)	9.8 (28%)
Non-intended	3.60 (71%)	1.50 (29%)	16.4 (70%)	6.9 (30%)

Note: In the Rayner et al. (2001) study, intended refers to ads that viewers were instructed to look at to purchase whereas non-intended refers to the other ads they viewed.

Figure Captions

Figure 1. Fixation duration frequency distributions for reading, scene perception, and visual search. The data are from the same 24 observers engaged in the three different tasks. No lower cutoffs of fixation duration were used in these distributions while an upper cutoff of 1000 ms was used.

Figure 2. Examples of a moving window (with a thirteen character window), a moving mask (with a 7 character mask), and the boundary paradigm. When the reader's eye movement crosses an invisible boundary location (the letter *n*), the preview word *house* changes to the target word *print*. The asterisk represents the location of the eyes in each example.

Figure 3. Examples of where viewers look in scenes. The top portion of the figure shows where one viewer fixates in the scene (the dots represent fixation points and the lines represent the sequence). The bottom portion shows where a number of different viewers fixate (with the dots representing fixation locations across a number of viewers).

Figure 1

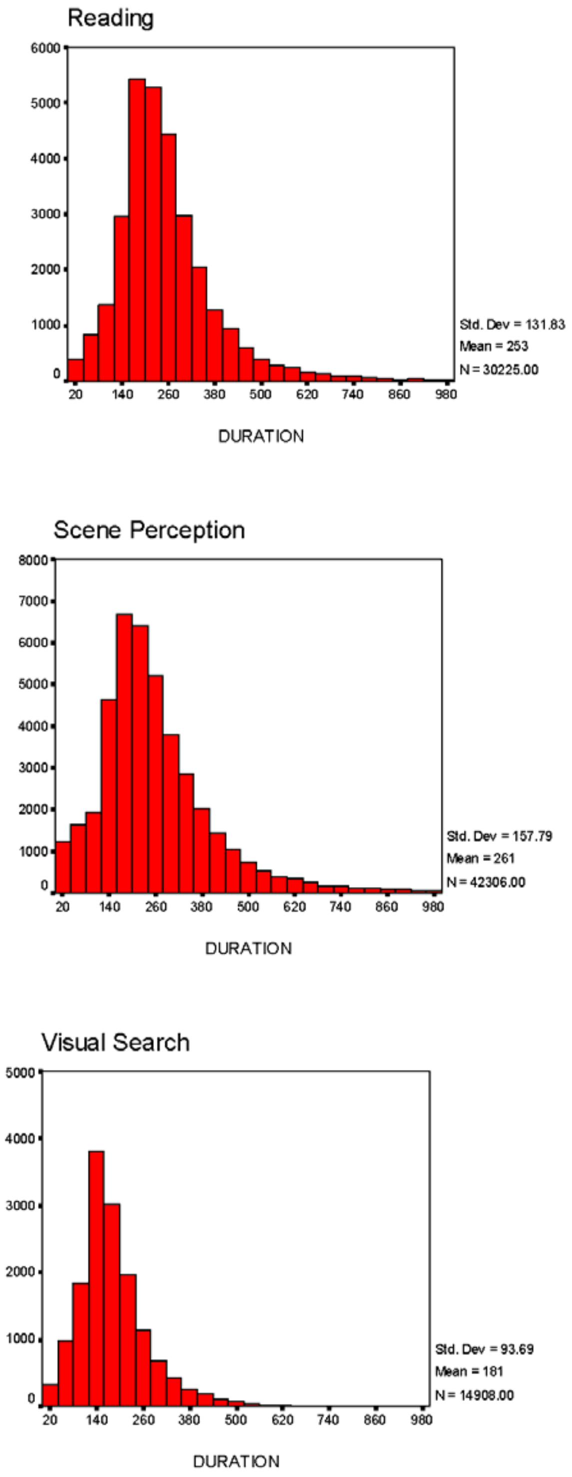
Reading
6000
5000
4000
3000
2000
1000
0
20
140
260
380
500
620
740
860
980
DURATION
Std. Dev = 131.83
Mean = 253
N = 30225.00
Scene Perception
8000
7000
6000
5000
4000
3000
2000
1000
0
20
140
260
380
500
620
740
860
980
DURATION
Std. Dev = 157.79
Mean = 261
N = 42306.00
Visual Search
5000
4000
3000
2000
1000
0
20
140
260
380
500
620
740
860
980
DURATION
Std. Dev = 93.69
Mean = 181
N = 14908.00

Figure 2

Normal Line:

```
do people look in print advertisements and
```

Moving Window Paradigm (13 character window):

```
Where xx xeople look inxxxxxxxxxxxxxxxxxxxxxxxxx
                *
Where xx xxxxxxxxxok in print axxxxxxxxxxxxxxxxx
                        *
```

Moving Mask Paradigm (7 character mask):

```
Where do people lxxxxxxxprint advertisements and
                    *
Where do people look in xxxxxxxdvertisements and
                           *
```

Boundary Paradigm:

```
Where do people look in house advertisements and
                  *
Where do people look in print advertisements and
                         *
```

Figure 3