The motion of the pen is more fluid and is not raised off the page.

Middle Yeh transforms to small raised hub and is extended elegantly across the baseline.

Double storey version of Qaf.

The final Zeh shape loses the top part and simply flows down from the previous letter.

The Nun middle form changes from straight stroke to simply an upward curve that rolls into the next character.

Kaf has different shapes. One is more extended and elegant.

Fig. 4.21 (both pages) Detailing of how Afsandem Dynamic (in white) is different from Afsandem Simplified (in black).
Fig. 4.22 (both pages)
Detailing of how Afandem
Dynamic (in white) is
different from Afandem
Simplified (in black).

Mim loses its inner space
and turns from circular
form to a small stroke
that doubles on itself.

Yeh transforms to small
rise in the stroke.

Raised Feh climbs on
following letter Yeh.

Extended version of Yeh
gives balance to the
complex form on top,
similar in effect to
swashes in Latin.

Raised Jem climbs on
following letter Yeh.

Raised Feh climbs on
following letter Jem.
زعموا أنَّ غديراً كان فيه ثلاث سمكات: كيسة النَّافِئِي (أَكِيسَ مِنْهَا، وَعَاجِزة). وكان ذلك الغدير بنجوة من الأرض، لا يكاد يرى بقربه نهر جار. فانتفَقَ أنَّهُ اجتاز بذلك النَّهْر صيادان، فأبصربا الغدير، فتوعدا أن يره بشباكهما، فيصيدا ما فيه من السمك.

زعموا أنَّ غديراً كان فيه ثلاث سمكات: كيسة النَّافِئِي (أَكِيسَ مِنْهَا، وَعَاجِزة). وكان ذلك الغدير بنجوة من الأرض، لا يكاد يرى بقربه نهر جار. فانتفَقَ أنَّهُ اجتاز بذلك النَّهْر صيادان، فأبصربا الغدير، فتوعدا أن يره بشباكهما، فيصيدا ما فيه من السمك.

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Fig. 4.23 comparison of the 3 variants of Afandem. From top to bottom: Simplified, Traditional, then Dynamic. Dynamic takes up the least space horizontally.
Fig. 4.24 (Both pages)
Comparison of the 3 variants of Alandem. From top to bottom: Simplified, traditional, then Dynamic. Each word is split into its separate letters (shown here in white). The Dynamic version is often more visually dense due to the manner in which the characters join to each other.
(Fig. 4.15). This variation is a big feature in manuscripts and, though possibly avoidable, was deemed to be essential for Aflandem Dynamic to be truly representative of this genre. Many of the typical character combinations would not be possible if not for the tighter spacing, and an overall tighter spacing would jeopardize the results. An overall tighter inter-character spacing would have an effect on reading speed as will be discussed in the next chapter, and the resulting visual composition would not be in full keeping of the manuscript tradition. In a way, it is almost as if calligraphers intuitively know that the words need to breathe, and they therefore elongate some characters or connecting strokes to give a bit of breathing space.

- Economy of space: Aflandem Dynamic takes up less space than Aflandem Traditional, which in turn takes up less space than Aflandem Simplified. The nature of combining characters, the fact that they often clump up, means that the more combination one has, the less space one needs for a given amount of text. In this specific case, the difference between all three styles was minor, though still slightly noticeable. The difference is most pronounced between the Simplified and Dynamic versions (Fig. 4.23).

- Density: Though close in density to the Traditional version, Aflandem Dynamic has a more compact density than that of the Simplified (Fig. 4.24). This is a natural byproduct of the combining characters and could not be avoided. However, a balancing factor is the fact that a tighter column width leaves wider margins i.e., more white space around to compensate for the denser composition.

- Word spacing: This was maintained as constant across the 3 styles (Fig. 4.23). Word spacing has an effect on reading speed as will be discussed in the next chapter and thus was left constant though calligraphic Nashi can sometimes be set tighter. However, this digression did not negatively affect the overall look and feel of Aflandem Dynamic.

- Overlapping swashes: This is another feature of manuscript Nashi that was significantly toned down. It is sometimes the case in manuscripts that the isolated or final forms of certain characters are extended and the swash extends underneath the next word. This overlap was seen here to be intrusive and a factor that could affect reading speed and was therefore minimized. There were some cases where the left-side tip of the swash was kerned with the following word though no major overlap was present. This was done to avoid white holes in the text, as that is the primary function of the overlap. In short, swash finalis were treated with restraint and caution (Fig. 4.23).

- Energetic base ribbon: Compared with the rather static Simplified version, and the moderately moving Traditional one, Aflandem Dynamic sits on an upbeat base ribbon that flows up and down like a real ribbon in a light summer breeze (Fig. 4.20). It would have been possible to have an even more energetic version, but this would have strayed too far from the other 2 styles.

Overall, Aflandem Dynamic is a middle ground solution to the problem at hand. If pushed towards more uniformity and less energy, it would stop being part of the genre it tries to represent. If pushed into more calligraphic abundance, it would then introduce too many variations that might confound the results. However, this is no way a problem. Manuscript Nashi is flexible and there are many different ways
Rhythm and proportion: The speed with which letterforms make up words, the overall word proportions, and the rhythm of the text are again very similar. Both rhythms are widely set, unburied, relaxed, soft, and generous in feel.

Horizontality: Afandem Dynamic maintains the smooth horizontality of the manuscript source, and offers a rhythm where the words sway very elegantly across the line rather.

Some changes: The design of Afandem had to depart from the manuscript source in some details such as the size of the small counters, such as in مه, and the positioning of the two dots in ه. It also shows lower contrast between thin and thick stroke, and this is to avoid the flickering effect when viewed on screen. Other than that, most of the small differences in detailing stem from the requirements needed to adapt the design of Afandem to the Simplified and Traditional versions.

When designing typefaces that refer to historical handwritten models, there are various design questions that come up in this process:

- How close should the typeface be to the source of reference? Are the curves drawn to be an exact replica, or are there any changes implemented? If yes, what are these changes and why have they been added? For what purpose is this typeface being drawn, and is it similar in function to that of the original?
- Afandem Dynamic is very close in design to its source of inspiration, but it is not an exact replica. The changes, as described earlier, were implemented specifically to leave room for the simpler versions to be designed, and also to make sure that this typeface is suitable for being read on screen. As will be described in Chapter 7, the text of the experiment is set in black on white and over a large screen. The typeface size is not so small that it creates reading problems, but it is still a context of a visual being displayed on screen. The function, then, is somehow different from that of a manuscript. This is the driver of change. The end result, as can be seen in Fig. 4.14, is a modern interpretation of the calligraphic origin: similar in design, and look and feel, but tweaked to work for contemporary usages.

**Designed for Reading**

At this point, a nagging question comes to mind: How much do type designers know about reading? There is irony in the fact that those who design text for reading are very different people from those who investigate how reading and eye movement actually works. The existence of the two groups is a problem as the skill sets and fields of expertise are quite different. However, the scarcity of contact between the two is troubling and quite detrimental to the efforts of both. Fortunately, this situation is slowly changing and there has been an increase in recent years in the number of type designers interested in legibility research. Contact between the two fields of study is improving.

It is in this mindset that we turn over to the next chapter and switch from design talk and the look and feel of type to psycholinguistics and the studies and findings and statistically significant results. The reason for this jump is simple, for we, no matter how skilled as designers, cannot say for sure which style is easier to read if we do not know how reading works in the first place.

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Fig. 4.26 Comparison of the original manuscript reference (top and middle) with Afandem Dynamic (bottom).

To render a piece of text. Some Naskhi manuscripts are calmer, and with a more open feel to them. The choice here was for an elegant and restrained version, one that is true to its genre but without the excesive calligraphic swash. This is true to the original Ottoman Naskhi sample by Mehmed Şelik Bey, which also shared these traits.

In effect, the complexity of word formation ended up triggering a chain of reactions that affected several aspects of the design. This was unavoidable and the utmost care was given to minimize this effect. However, at the end of the day, these changes are what make the Dynamic version more complex than the other two. They are part and parcel of the same issue: a complex word formation mechanism will bring about certain visual characteristics that are different from a simpler and more straightforward formation.

From the first steps of the design of the Afandem family, the typeface design was heavily influenced by the shapes and proportions of the original manuscript source. This is evident in the design of the isolated contextual shapes even in the Simplified and Traditional versions. The elegance of movement seen in the manuscript left a trace in its typographic adaptations. During the design of Afandem Dynamic, the typeface was continuously tested against its original source of inspiration. The typeface and its manuscript point of reference are related in many aspects of their design and visual impact (Fig. 4.26):

- Letterform design: Afandem is highly influenced by the shape, structure, and proportion of the Mehmed Şelik Bey reference. There are some minor differences, but the overall look and feel is quite similar.
Chapter 5

Eye Movement and Legibility Studies

The previous chapters have looked at the Arabic script, its calligraphic and typographic developments, and the state of Arabic type design today. All of that was being analyzed and observed with the eyes of a designer. This chapter is a departure from that arc. Here we turn to the study of reading and eye movement. It is a literature review chapter belonging to the domain of psycholinguistics. The aim is to understand eye movement in reading, the effects of the legibility of type on eye movement, and what legibility studies have discovered so far.

The chapter will attempt to give an overview of the findings of eye movement studies. It starts with the pattern of eye movement in reading, its characteristics, what facilitates, and what hinders it. It also investigates the effects of language and different script systems on reading. It explores how the nature of the content affects the reader’s eye movements, and how the reader in turn can react differently to the text. It looks at what is in focus, and what is not, and how these two interact and drive the eye forward. That leads to the questions of where and when to move the eyes, and the big debate of eye movement control.

Having studied the patterns of eye movement and how the characteristics of both the reader and the linguistic material being read affect reading measures, the final section shifts to the effects of the visual characteristics of the text on eye movement and reading measures. That section will give an overview of legibility findings, as well as methods of carrying out legibility studies.

Why is this chapter important to this dissertation? There is no Arabic in it, but it is the middle piece of the puzzle. For one to understand how the visual characteristics of a script affect reading, it is important to understand how reading works, and how different scripts and languages affect the reading process, and what makes a legible design. The reading and legibility studies specific to Arabic have been relegated to a separate chapter coming up next, but for now, it is time to get back to reading.

The Mechanics of Eye Movement

In its simplest definition, eye movement is made up of stops and jumps, called fixations and saccades respectively. Fixations are the instances when the eyes stay relatively still in order to focus on a visual stimulus. Saccades are fast movements during which reduced information intake is obtained due to what is generally referred to as saccadic suppression (Rayner & Pollatsek, 1983). The eyes move so quickly that any information taken in during a saccade would be seriously blurred; the masking effect of clear and sharp information acquired before and after a saccade removes the perception of blurring (Brooks, Impeimaa, & Lumi, 1991).
Eye Movement and Legibility Studies

**Eye Movement in Reading**

Eye movement in reading is a series of stops and jumps. 3-4 letters

Saccade: Duration: 30-60 ms 2-3 jumps

Eye movement in reading is a series of stops and jumps.

Regression: 10-15% of saccades

Eye movement in reading is a series of stops and jumps.

Eye movement in reading is a series of stops and jumps.

Reading area: 5-13 letters

Reading area: 5-13 letters

It is necessary to frequently move our eyes due to limitations in our visual acuity. When looking straight ahead, one has around 2 degrees of a sharp visual (corresponding to objects falling on the fovea), then up to 5 degrees of less clear vision (for objects falling on the paralelaxa), and then it gets to be of much poorer quality as it extends out (for objects falling in the periphery) (Rayner, 1998). It is then necessary to keep moving the eyes so that the visual that we want to focus on falls onto the fovea, which is the central part of the eye's retina.

The movement of the eyes is tied to how the visual system behaves during reading. However, reading is a much more complex process, and the process of reading involves many different stages of analysis. This will be discussed later on in this chapter. For now, it is good to keep in mind a general overview of what is going on in the cognitive processing of text:

"First, visual information is obtained, and the orthography (letter identity and word length), phonology (sounds), and morphology (units of meaning, grammatical gender, etc.) of the word are analyzed. Then the lexical representation (the abstract representation of the word form) is accessed. Finally, the semantic (word meaning) and syntactic (grammatical role) representations of the word are accessed and integrated into the meaning of the sentence" (Schottter, Angele, & Rayner, 2012, pp. 7-8).

Eye Movement in Reading

Eye movements in reading are comprised of fixations and saccades (Fig 5.1). Fixations in English usually last for around 225-250 ms but can vary greatly from as short as 50 ms to 600 ms or more; the average saccade is 7-9 letters but can also range from as little as 1 letter to up to 20 letters or more (Rayner, 2009). The average saccade corresponds to a 2 degree move and usually takes around 30 ms to execute (Rayner, 1978). These values, though, are averages and can vary across individuals. The difficulty levels of the text material and the reading skills also have a direct effect on reading measures; the more difficult the material is, the longer the fixations, the shorter the saccades, and the more regressions are made (Rayner, 1998). Indeed, the variability seen in fixation durations is mainly due to the level of difficulty of the text being processed (Rayner & Duffy, 1986) and is reflective of on-line processing (Rayner, 1998). Reading measures are also affected by the nature of the script and the typographical qualities of the typeface used as will be discussed later in the chapter.

Saccades are usually forward movements that move the eyes forward through the text to bring in new stimuli to the fovea. However, around 10-15% of saccades bring the eyes backwards in what is usually referred to as regressions (Fig 5.1). Regressions usually go back one word either because of oculomotor errors where the eyes landed too far from their intended target, or because of the need for further lexical processing (Rayner, Chico, Slattery, & Ashby, 2006). However, the eyes do tend to go back even further into the text when faced with comprehension difficulties (Rayner, 2009). Regressions within the same word also occur, and those are due to difficulties processing the currently fixated word (Rayner, 1998).

Around 77% of regressions within the same line of text are going back a few characters within the same word, or to the word directly preceding it (Vituu, 2005) (Fig 5.1). Within-word regressions are around 2 letter spaces and inter-word regressions are around 3-4 letter spaces (Vituu & McConkie, 2000). Both of these kinds of regressions are not sent randomly back in the text but rather to specific word positions (Vituu, 2005), and they tend to land in the center of the word (Infoff, Weger, & Radach, 2005). On the other hand, long-range regressions are directed in the general direction of the text to be read, guided by the reader's knowledge of content and word order, and are then followed by another saccade that brings the eyes to the intended location (Infoff et al., 2005).

It is also interesting to note that readers can recall the spatial location of information that they have just read, (Infoff et al., 2005) and this might assist in the planning and execution of regressions. Studies have also shown that a regression is more likely if the directly preceding saccade was long, if the origin word was of low frequency, or if a word had been skipped; this is especially so, if the skipped word was long or of low frequency (Vituu, 2005).

Other than comprehension difficulties and mislocated fixations and research has shown that around 20% of fixations are mislocated (Inghburt, Nuttermann, & Kliegl, 2007)—regressions could be due to ambiguities within the text. Reading could be proceeding smoothly until the reader comes across a word that reveals a different interpretation of the sentence is needed; tests have shown that readers in such cases often make a regression as soon as they come across the disambiguating word (Frazier & Rayner, 1982). However, the pattern of regressions did not show that the readers went back to the beginning of the sentence, nor did it show a systematic backtracking until the source of error was found. Rather, the pattern was indicative of a system of selective re-analysis using whatever available information about the error that there is in (Frazier & Rayner, 1982).

Other forms of saccades are return sweeps. These are movements that bring the eye from the end of one line to the beginning of the next one. In left-to-right

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1 For the rest of this chapter, all discussions of reading refer to silent reading, and when unspecified, usually refer to the reading of English since most of the work done in this field has been done with the English language.

2 If the regression happened after fixation on word n, and there was no previous word skipping, the origin word would be word n+1 (Vituu, 2005).
scripts, this would be a right-to-left movement and vice versa. These are column-wide movements and are therefore often long ones. The eyes frequently undershoot and end up doing small corrective movements towards the beginning of the line; the first and last fixations on a line are not at the extremes but at around 5-7 character spaces inwards (Fig. 5.1) and so roughly 20% of the text fall outside the reading area (Rayner, 1998). Words at the line extremes are not the only ones being skipped. Within the text falling between the 2 extremes, other words are also being skipped. In general, only 85% of content words are fixated, while the number drops to 35% of function words; in other words, 65% of function words are skipped (Rayner, 2009).

**Tremors, Drifts, Microscasades**

Even during a fixation, the eyes are never really still (Rayner, 1998) and there are 3 types of movements other than the saccades already discussed: drifts, microscasades, and nystagmus (also referred to as tremors).

During a fixation, the eyes make small movements that are generally involuntary and rarely more than 1 degree in amplitude (Engbert & Kliegl, 2004). The eyes drift with slow and small movements (drifts) due to lack of perfect control of eye movement by the nervous system (Rayner, 1998). Microscasades, which are fast and small involuntary movements, bring back the eyes to the original position (Rayner, 1998). Microscasades are about 25 ms in duration (Martinez-Conde, Macknik, & Hubel, 2004) and help in reducing binocular disparity (Engbert & Kliegl, 2004) which will be discussed in the following section.

Nystagmus is small but constant tremors. Their nature is not clear but is assumed that the eye keeps moving so as to maintain perception and to help keep the nerve cells in the retina active (Rayner, 1998). If the eyes were perfectly still, the visual perception would fade because of neural adaptation (Martinez-Conde et al., 2004). These tremors are the smallest of all eye movements, are independent in the 2 eyes, and are simultaneous with drifts (Martinez-Conde et al., 2004).

**Binocular Fixation Disparity**

Contrary to what one might expect, the two eyes do not land on the same letter during reading. Instead, each eye can fixate on a different letter. This phenomenon is referred to as binocular fixation disparity. In some cases, the eyes are even crossed: the left eye lands to the right of where the right eye has landed. Livermore, White, Findlay, and Rayner (2006) have shown that the eyes are in fact aligned for only 53% of the time and, in these cases, are within 1 character of one another. This roughly corresponds to 0.25 degrees of the visual angle, for the remaining 47% of cases, the disparity is close to 2 characters. These values refer to disparity measured at the end of the fixation. Binocular disparity is larger at the beginning of a fixation, where vergence movements help to bring down disparity during the fixation. The magnitude of these vergence movements is positively correlated with the fixation duration (Liverwedge et al., 2006). The velocity of these vergence movements is positively correlated with the content of saccades, with faster vergence movements after long saccades (Colliwijn, Erkelen, & Steinman, 1988) and after reading for comprehension (Hendriks, 1996).

Binocular disparity is more obvious in children than adults, and with a higher number of crossed fixations (Blythe et al., 2006), but this is not affected by either the visual or the linguistic characteristics of the text, or whether the task was reading or not even linguistic in nature (Julias, Livermore, White, & Rayner, 2006). Furthermore, binocular disparity was found to be not affected by fixation times (Julias et al., 2006) and was not affected by the frequency of the currently fixated word (Blythe et al., 2006). However, binocular coordination was found to have a more critical role in the foveal than in the parafoveal region (Blythe, Livermore, & Findlay, 2010). The "effective fusion range," needed in order to form a "single unified perceptual representation" of the text, is when binocular disparity is 1 character apart: more than that results in decreased accuracy, and more fixations and trials (Blythe et al., 2010). This would have a resulting effect on the probability of refixations.

**Effect of Script on Reading Measures**

The writing system is one of the major contributing factors to the differences in reading measures across different languages. For example, the Chinese script is ideographic where words are made up of one or two character so the script density is quite high compared to English. The average fixation duration and regression rate for Chinese are similar to that of English; the average saccade length, though, is quite different where the readers move their eyes an average of 2-3 characters, rather than 7-9 (Rayner, 2009). Similarly, saccade length in Japanese is about 2-5 characters (Ikeda & Saida, 1978). Of the different Japanese script systems, katakana requires the longest fixation duration and shortest saccade length (in terms of space rather than character count) and kanji-based text requiring the longest saccade and shortest fixation duration (Osaka, 1989). It is possible that katakana is the most labor intensive since it is used for the transcription of foreign words, which are by nature less frequent. It is though puzzling why kanji, which is based on Chinese logographic characters and is the most linguistically dense, results in longer saccades. It is the only exception to the Rayner’s (2009) observation that the increased density of linguistic information decreases the saccade length.

This effect of linguistic density on reading is also seen in Hebrew. Like Arabic, everyday Hebrew text is unvaluated (undotted, in this case). Because the vowels are dropped out, Hebrew texts are then denser than English ones. As can be expected, saccade lengths in Hebrew are shorter than English ones, with 3.5 letter spaces on average; the speed of acquisition of Information (as in words per minute) were similar but the Hebrew fixation duration average is slightly higher than that of English (Pollatsk, Bozoky, Well, & Rayner, 1981).

All these results with regards to linguistic density are in line with the findings of Morrison and Rayner (1981) which showed that the saccade length in fact depends on the character spaces and not visual angle. They showed that when type size is maintained constant, the saccade length stays the same even when the distance from the stimulus is doubled. They conclude that the number of characters is an appropriate measure for saccade length (R. Morrison & Rayner, 1981).

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3 The relative linguistic density within the Japanese writing systems and their affect on saccade length remains to be studied.

4 It is necessary to point out here that these tests are usually conducted in monospaced typefaces so all characters have the same advance width. Monospaced typefaces by definition have equal widths for all characters (wider ts and lighter m’s). The fact that all characters have the same widths means that it is to say the character on the left of saccades as the character width is always constant across the lineface so words with this letters like the word “is” will have the same width as words with wide letters like “nam.” In a proportionally spaced typeface, this would not be the case.
### Eye Movement and Legibility Studies

<table>
<thead>
<tr>
<th>Perceptual span</th>
<th>Eye movement in reading is a series of stops and jumps.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>8-15 letters</strong></td>
<td><strong>10-15 letters</strong></td>
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<table>
<thead>
<tr>
<th>Area in which words can be identified</th>
<th>Eye movement in reading is a series of stops and jumps.</th>
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</thead>
<tbody>
<tr>
<td>7-8 letters</td>
<td><strong>10-15 letters</strong></td>
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<table>
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<tr>
<th>Area in which words shape and letter information are changed</th>
<th>Eye movement in reading is a series of stops and jumps.</th>
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</thead>
<tbody>
<tr>
<td>8-10 letters</td>
<td><strong>10-15 letters</strong></td>
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**Attention, Perception, and the Parafeovea**

When we read, it appears as if the whole line is in focus. In reality, only a part of the line is within our perceptual span (Fig. 5.2), also called the field of effective vision. In English, this field is asymmetric and extends to 3-4 characters to the left of the fixation (McConkie & Rayner, 1976) and 14-15 characters to the right of it (McConkie & Rayner, 1975). A reduction in the field of effective vision, manipulated via the moving window technique, results in longer fixation times, more forward saccades, but has no effect on the number of regressions (McConkie & Rayner, 1975). The area in which words can be identified, usually referred to as word identification span (Fig. 5.2), is smaller than the perceptual span and is around 7-8 characters right of the fixation (Rayner, Well, Pollatsek, & Bertera, 1982).

Though the field of effective vision spreads to 15 letter spaces to the right of the fixation, the reader does not obtain word shape or specific letter information (Fig. 5.2) until around 10 letter spaces right from the fixation (McConkie & Rayner, 1975). The field of effective vision is bound by the currently fixated line and does not extend to the lines underneath; the only exceptions are in the case of a visual search task, or if the text is arranged to read vertically as in Chinese and some versions of Japanese (Rayner, 1998). However, there is a vertical downward pull of saccadic trajectories that is reflective of a top-to-bottom orientation of attention (Inhoff, Seymour, Schad, & Greenberg, 2010).

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5 Studies related to the perceptual span usually make use of the moving window technique to calculate and manipulate the size of the area of effective vision.

6 This quote from Rayner gives further details on the technique: “In the moving window technique (McConkie & Rayner, 1975), the text is perturbed except in an experimenter-defined window region around the point of fixation. Wherever the reader looks, the text is visible, while outside of the window area, the text is perturbed in some way. Readers are free to move their eyes whenever and wherever they wish, but the amount of useful information that is available on each fixation is controlled by the experimenter. Each time the eyes move, a new region of text is exposed while the region previously fixated is perturbed. In some cases, the window is defined in terms of letter spaces, whereas, in other cases, the window coincides with word boundaries. Sometimes the spaces between words outside of the window are preserved, and other times they are filled in, and sometimes the text is perturbed outside the window only on selected fixations. The assumption with this technique is that when the window is as large as the region from which the reader can obtain information, there is no difference between reading in that situation and when there is no window” (Rayner, 1998).

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The perceptual span, then, is asymmetric (McConkie & Rayner, 1976) and biased in the direction that the attention is moving in (Reichle, Rayner, & Pollatsek, 2003) as can be seen in the perceptual spans of Israeli subjects reading Hebrew and English (Pollatsek et al., 1981). Pollatsek et al. (1981) very clearly demonstrated that the perceptual span in Hebrew is also asymmetric but that it is biased to the left rather than to the right, a result which corresponds to the direction of reading and therefore attention. This result is interesting for several reasons: 1. The same readers showed a biased perceptual span to the right when reading English, and so the perceptual span is not a product of reading habit but reading direction; 2. As argued by the authors, this is valid proof that the asymmetry is due to reading direction and not hemispheric specialization and thus quelling the argument that the span is biased to the right so as to bring in more information to the left side of the brain; 3. This is solid evidence to the effect of the script system on the mechanics of reading.

Studies of the perceptual span across various scripts have shown that the size of the field of effective vision is also script dependent. For example, in Japanese, the perceptual span is around 10 characters (Ikeda & Saldaña, 1978), though later studies have put that number as 7 characters for kanjihirakana mixed text and 5 characters for hirakana (Osaka, 1992). The same study also found shorter saccade lengths for hirakana. Both these are puzzling since the kANJI letters are more visually complex and one would expect that to translate into a tighter perceptual span, since it usually does have a decreasing affect on saccade length (Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006) as will be discussed later. The 7 characters for the kanji-hirakana mix correspond to having a preview of the currently fixated word and the beginning of the next one, which is less than what one usually gets during the reading of English texts (Inhoff & Liu, 1998).

In Chinese, the perceptual span is also asymmetric and extends one character to the left and 2-3 characters to the right (Inhoff & Liu, 1998). Inhoff and Liu (1998) have demonstrated that Chinese readers need a valid preview of up to 3 characters to the right in order to achieve normal saccade lengths, landing locations, and gaze durations, but up to 2 to achieve normal fixation durations. The 3 characters correspond to the currently fixated word and the one to the right of it, thus larger than the Japanese kanji-hirakana perceptual span (Inhoff & Liu, 1998).}

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7 “Hirakana are phonetic symbols for syllables, whereas kANJI are essentially nonphonetic symbols, or ideograms, representing lexical morphemes. KANJI characters are more complex patterns (involving relatively higher spatial-frequency components and are more iconic in form)” (Osaka, 1992).
span than slow ones whose perceptual span comprised the fixated word and one right after it only (Rayner, Slattery, & Bélanger, 2010).

When it comes to beginning readers, Rayner (1986) found that their perceptual span is smaller, asymmetrical to the right, and goes for about 11 letter spaces to the right of fixation. An interesting finding from this study was that beginner readers did not use any of the word boundaries in the parafovea in order to program the next fixation. However, perhaps the most interesting findings in this study was that the difficulty of the text reduced the size of the perceptual span and that the span is symmetrical to start with but gets biased after just one year of reading (Rayner, 1986). This is further evidence that the perceptual span is not a product of visual acuity but rather a result of the script and linguistic characteristics of the text being read. This was further supported by the finding that the amount of parafoveal benefit extracted during a fixation and the size of the perceptual span are both dependent on the specificities and the difficulty level of the reading task at hand (Bahlof, Pollatsek, Puzzer, & Rayner, 1989). Perhaps the most eloquent description with regards to the perceptual span is given by this quote: "...attention and ongoing processing constraints, and not visual acuity, determine how much information can be obtained on each eye fixation in reading" (Rayner, 2009).

A last note regarding the size of the perceptual span in beginning readers. Rayner (1986) was able to show that it is not its smaller size that results in slower reading in beginning readers. Rather it is that the longer fixation durations, shorter saccades, and the larger number of fixations and regressions are due to the beginner’s extra effort needed for word recognition and cognitive processes. He further concludes that the eye movement measures are a reflection of that rather than the cause of it. As to older readers, their perceptual span is smaller and more symmetrical, indicating a less efficient capability of processing words in the parafovea (Rayner, Castelhano, & Yang, 2009). The question here would be, is this due to lower visual acuity or working memory? The authors maintain that it is due to the loss in visual acuity with age, and the increased time needed for foveal processing, which leads to less capacity to give to parafoveal processing (Rayner et al., 2009). As such, visual acuity is not the defining factor in how big the perceptual span is. However, it is a modulating factor during the lifetime of a reader.

Another argument against the role of visual acuity in defining the perceptual span was given by Miellet, O’Donnell, and Sereno (2009). They systematically increased the size of characters as they were further away from the fixation location to compensate for the loss in visual acuity. What they found was that the perceptual span remained at 15 characters to the right of fixation and so impenetrable to the improvement to the visual quality of the stimulus in the parafovea (Miellet et al., 2009). This is consistent with an earlier study that had also found that increasing letter sizes in the parafovea did not take away the viewing position effects and did not improve reading performance (T. Nazir, Jacobs, & O’Regan, 1998).

Parasaccadic Preview Benefit and Effects

Fixation durations can decrease by around 30–50 ms if the reader has a valid preview of the word that comes to the right of the currently fixated word. This is usually referred to as the parasaccadic preview benefit. It involves collecting information regarding the position of letters within words, the abstract coding of letters (doesn’t matter if uppercase or lowercase), as well as orthographic and phonological coding. This information is integrated across saccades (Rayner, 2009) and can affect the duration of the fixation on word n+1.

Eye movement in reading is a series of stops and jumps. After 50–60 ms, the fixated word disappears but the eye remains in the same position. Eye movement is a series of stops and jumps. And reading continues smoothly. Eye movement is a series of stops and jumps. However, some characteristics of the text are not. Studies have shown that neither semantic information (Altarriba, Kambe, Poltke, & Raymer, 2001) nor low level visual featural information such as the letter case (Rayner, McConkie, & Zola, 1980) are integrated across saccades. Therefore, the extracted visual information from the preview of word n+1 has no effect on the fixation duration on that word (Rayner et al., 1980). This is in line with the findings that when letters are identified via their features, the visual information is very quickly stripped and abstract letter codes remain (Grainger, 2008).

With regards to the integration of morphological information, there is no evidence for that in English (Juhasz, White, Liverdige, & Rayner, 2008) or Finnish (Bertsim & Hyvönen, 2007), but there is in Hebrew (Deutsch, Frost, Pelleg, Pollatsek, & Rayner, 2000). Similar to Arabic, Hebrew verbs and most nouns are built around 2 morphological entities, the root and the pattern. The root holds the semantic meaning of the word and was found to have a priming effect when word n+1 had the same root as word n (Deutch et al., 2003). The processing of words in the parafovea occurs irrespective of word position in the sentence, and so there is a preview benefit for words at the beginning, in the middle, or at the end of sentences (White, Warren, & Reichle, 2011). The ignored benefit is higher when the currently fixated word is easy to process and lower when it is difficult (Henderson & Ferreira, 1990). Moreover, the effect of the difficulty of processing the currently fixated word on the preview benefit is not a spillover that is the result of a fixation that was too short; In fact, this effect was seen for both short and long fixations (White, Rayner, & Liverdige, 2005).

Quite interesting and contrary to what one might expect, the reader needs only around 30–60 ms of exposure to the currently fixated word in order for reading to continue smoothly (Fig. 5.3). That is to say, if a word was masked or disappeared after 50 ms of the eyes landing there, reading would continue without any disruption (Rayner, Inhoff, Morrison, Slowaiczek, & Bertera, 1981). This is not to imply that word processing is done within that short of a time frame, but rather than the visual information that needs to be extracted from the word is done very quickly and very early on in the reading process (Reichle et al., 2003). The eyes remain in place even when the target word has disappeared, and the eye will move on within the same pattern of eye movement as if the target word was still there (Rayner, Liverdige, & White, 2006). The ability to continue reading even when the target word dis-
appeared after such a short time was also valid for reading in Chinese, and with similar exposure times (Zhuang, Guori, & Xuejia, 2011).

Also interesting was the finding by Rayner, Liversedge, and White (2006) that if the word right of the fixation at n+1 were to be masked or disappeared when the eyes land on word n, or even after 60 ms of landing there, reading rates are disrupted. Furthermore, the reader needed to have a valid preview of word n+1 throughout the fixation on word n, or at least for the whole duration after 60 ms of landing there and the masking of word n+1 had a more disruptive effect than its disappearance (Rayner, Liversedge, et al., 2006). This is further indication of the importance of parafoveal preview.

The next question that follows: how much of word n+1 does one need in order to get a parafoveal preview benefit? A study looking at what would constitute useful information in the parafovea found that readers only needed to have the first 3 letters of word n+1 in order to get almost the same preview benefit as they would have if shown the full word (Rayner et al., 1992). This implies that the preview benefit is not necessarily tied to the identification of whole words but rather to the beginning part, most likely as an initiative for lexical access (Rayner, 1998). The parafoveal preview benefit is also responsible for skipping words. These are usually very short (for example, function words such as of, the, and etc.) or highly predictive in the context (Rayner, 2009). In the case of highly predictable words in the parafovea, the parafoveal preview extends to more than just 3 letters; moreover, readers are just as likely to skip a nonword if it is visually similar to a highly predictable word according to the sentence context (Balota, Pollatsek, & Rayner, 1985).

The idea that one does not need a full preview of the word for parafoveal preview benefits to kick in is not surprising given the results that have shown that neither semantic nor morphological information are integrated across saccades. It is also then not surprising that the frequency of word n+1 yields no preview benefit for the fixation duration on word n (Rayner, Fischer, & Pollatsek, 1998). However, recent studies have shown that the frequency of word n+1 does play a role (Reingold, Reichle, Glaholt, & Sheridan, in press). They tested the effect of the frequency of word n+1 on the fixation on word n and found that this effect starts to become evident at 145 ms from the start of the fixation.

While readers of English do not get a preview benefit from word n+2 (Rayner, Juhasz, & Brown, 2007), studies have shown that Chinese readers do obtain a preview benefit from up to 2 words to the right of fixation. The Chinese script is based on box-like characters that, unlike alphabetic scripts, are the morphemic entities of the Chinese language. Words are usually made up of 1 or 2 characters and there are no word spaces. The parafoveal preview effect was seen for both words n+1 and n+2 irrespective if these made up 1 or 2 words (J. Yang, Wang, Xu, & Rayner, 2009). Further research has shown, though, that this is valid when word n+1 is a high frequency word; in the case when word n+1 is a low frequency word, this benefit will disappear (J. Yang, Rayner, Li, & Wang). Furthermore, neither semantic nor orthographic information can be extracted from the preview benefit of word n+2 (Yao, Kliegl, Shu, Pan, & Zhou, 2000).

Finally, the answer as to why the parafoveal preview is so important to reading could come from the way language itself is organized. As McDonald and Skillock (2003) explain, a reader's mastery of a language is dependent on his/her grasp of "word-to-word contingency statistics," the probability of one word occurring after another such as the preposition or occurring after the verb nly. This statistical knowledge is used by the brain during online processes and helps in forming predictions for upcoming words, contributing thus to efficiency in reading (McDonald & Skillock, 2003). This effect was thought to be independent of predictability effects, but later studies were able to show that it is not (Frison, Rayner, & Pickering, 2005).

**Parafocal-on-foveal Effects**

The extent to which the word right of fixation affects the fixation duration of the currently fixated word is called the parafocal-on-foveal effects. Results of various studies regarding the effects of the lexical and word frequency characteristics of word n+1 on the fixation duration on word n have so far been controversial and with mixed results (Rayner, 2009).

With regards to the effect of orthographic characteristics, there has been some cautious agreement. Several studies found an effect of the orthography of the word right of fixation on the fixation duration of the fixated word (Rayner, 2009). For example, Dreinge et al. found that a longer word in the parafovea led to a shorter fixation duration on the currently fixated word (Dreinge, Blyshbaert, & Desmet, 2005). Another study by Dreinge, Rayner, and Pollatsek (2008) also showed evidence for parafocal-on-foveal effects with results pointing to longer fixation times on word n when the word right of fixation [n+1] was orthographically illegible, the fixation position was very close to n+1, and the fixation followed a long saccade. This effect was attributed to mislocated (undershoot) fixations. The frequency of word n did not appear to have any effect in this study (Dreinge et al., 2008). Other studies such as the one carried out by Rayner et al. did not find evidence for parafocal-on-foveal effects (Rayner et al., 2007).

Researchers, therefore, are still far from reaching an agreement regarding the effect of word n+1 on the fixation on word n. Irrespective of what is or is not being processed of the parafocal word, it seems that the reader has certain expectations of what that word needs to be: when the parafoveal word is implausible, I.e. against the expectations set by the text, fixation durations will be increased (Murray, 1998).

**Effects of Age and Reading Skills on Reading**

**Age**

Reading measures, strategies and habits seem to change through one's lifetime. Studies have shown that older readers are slower in reading and make more fix-
ations and regressions (Kemper, Crow, & Kerns, 2004) and have longer saccades (Rayner, Reichele, et al., 2006).

When two age groups were tested for the effect of word length, frequency, and predictability on eye movement, a 47 average year in age difference still yielded many similarities though there were also a number of differences. Older readers read more slowly and were more likely to regress. They responded more consistently to word frequency. The effect of frequency on the probability of word inspection also gave different results. It increased skipping in the younger group, and decreased the likelihood of multiple fixations in the older group (Kliegl, Graff, Reichele, & Lang, 2004). Older readers, though, are generally more likely to skip target words than younger readers. This is much more pronounced for high frequency target words than low frequency ones and results in longer saccades for the older readers. Younger readers are equally inclined to skip either (Rayner, Reichele, et al., 2006).

Overall, it seems possible that older readers adopt a probabilistic reading strategy in that they use parafoveal information to skip words in order to get through the text quicker; however, this results in them having to do more regressions to clarify the areas of the text that have not been fully processed (Rayner, Reichele, et al., 2006). In relation to legibility researchers found no interaction between age and font style, but did show an effect for size: older readers needed larger sizes for minimum acuity levels (Connolly, 1998). In other words, the older the readers are, the less able they are to read type in small sizes.

Reading Skills

Reading skills also play a role in the process of reading. Ashby, Rayner, and Clifton (2005) compared the average reader with the highly skilled one and their results were quite interesting: 1. The average reader needed more time to recognize low frequency words that were unpredictable in the sentence context. 2. When the context was predictable, they relied on the context to obtain meaning and moved their eyes away from these low frequency words even before they were fully processed. 3. The highly skilled readers took a different strategy by rereading earlier parts of the sentence and working to integrate these words into the overall picture.

Effects of Language on Reading Measures

Difficulty

As mentioned early on in this chapter, the context of the text being read has an effect on reading measures. Difficult text results in longer fixations, shorter saccades, and more regressions; Indeed, researchers find that fixation duration is a good indicator of the ease or difficulty that the reader is facing in processing the fixated word (Rayner & Duffy, 1986). However, difficulty level is not the only way in which the linguistic content affects reading. Below are other factors.

Word Length

Longer words get skipped less often and are more likely to have multiple fixations (Kliegl et al., 2004). The number of fixations on a word are positively related to its length (Rayner & McConkie, 1976). A recent study (Hautala, Hyltin, & Aro, 2011) that asked the effect of word length and character count in both monospaced (Courier) and proportional width (Arial) typefaces found that the number of letters increases the fixation duration but has no effect on the skipping probability. On the other hand, the spatial length of a word played a role in fixation positions and the likelihood of skipping (Hautala et al, 2011). There are many typographic variables that come into play when one tests with a sans serif vs. a monospaced serif typeface so these results need to be looked at with caution.

Predictability

Subjects were found to be more likely to skip a target word when it was highly constrained by the context; when they did fixate on it, the fixation duration was lower for a predictable word than for an unpredictable one (Erlitch & Rayner, 1981). Predictable words are also less likely to have multiple fixations (Kliegl et al., 2004).

Predictability effects also extended to the parafovea. Parafoveal words that were highly predictable enabled a more detailed "parafocal visual information" to be obtained (Balota et al, 1985).

Research involving Chinese readers gave similar results. Fixation durations on low predictable words were higher than medium or high predictable ones, and they were more likely to be fixated on (Rayner, Li, Juhasz, & Yan, 2005).

Skipping

As mentioned in earlier sections, shorter words get skipped more often than longer ones and the skipping probability is around 80% for a one-letter word, 60% for a three-letter word, 45% for a four-letter word, and 30% for a five-letter word (Vitu, O'Regan, Inhoff, & Topolski, 1995). These averages increase if the launch site was 2-4 letter spaces away from the initial letter of the skipped word, and they drop if the launch site was farther than 4 letter spaces (Vitu et al., 1995). High frequency words get skipped more than low frequency ones (Kliegl et al., 2004).

Predictable words are also skipped more frequently than similar looking words that are not as predictable (Drieghe, Rayner, & Pelli, 2006). Though both word length and predictability have strong effects on skipping probability, these two variables do not interact i.e. they are independent of one another (Rayner, Slattery, Drieghe, & Luevnesge, 2011). As for the effect of syllables, and when controlled for overall word length, a mono-syllabic word is 5% more likely to be skipped than a bi-syllabic word (Fitzsimmons & Drieghe, 2011).

There is, also, another reason why words are skipped. The reason is simply due to errors in programming. Sometimes there are ocular motor errors in programming and executing saccades. This results in overshooting when the target word is near, or undershooting when the target is far (McConkie, Kerr, & Dyre, 1994). In both cases, the word n+1 ends up being skipped by mistake.

Though the preview benefit is tied to word skipping (Rayner, 2009), and the more difficult a word is, the less preview benefit the reader gets (Reichele et al., 2002), it has been shown that the foveal load (the difficulty of processing of word n) has no effect on the probability of skipping the following word n+1 (White, 2007). As to what happens after skipping, as reported in Brysbaert, Drieghe, & Vitu (2005), there are two possible scenarios. If the saccade was launched from word n, skipped over n+1 and landed on n+2, empirical evidence points to longer fixation durations for
the word n=2. Alternatively, the fixation on word n=2 is rapidly followed by a regression back to word n=1 (Brybaert et al., 2005).

More on the linguistic/conceptual difficulty of the text

As mentioned earlier, linguistically difficult text results in higher average fixation durations, a larger total number of fixations, and the overall reading time. Nevertheless, the size of the effect of average fixation duration is quite small. The extra reading time needed for difficult content results from the increase in the number of fixations (Rayner, Chace, et al., 2006). Difficult text also results in shorter saccades and more frequent regressions (Rayner, 1998).

Frequency

Low frequency words require longer fixation times (when matched for word length) and increase the gaze duration on the word right of fixation (Rayner & Duffy, 1986). High frequency words are also more likely to be skipped (Kliegl et al., 2004). Therefore, not only do high frequency words require shorter fixation duration, they also provide readers with a more effective preview benefit (Inhoff & Rayner, 1986).

In the studies of reading disappearing text as mentioned earlier, frequency effects still had an effect on fixations times. High frequency words required shorter fixation durations, and this effect remained in place, even when the target word n disappeared after 60 ms: the eyes remained in place even when the target was no longer there (Rayner, Liversedge, et al., 2006). Readers are also more likely to relink low frequency words (Rayner, Sereno, & Raney, 1996).

Effects of Morphology

Are words recognized as whole-words or do root morphemes play a role? The simple answer is that it depends on the language. For example, Beanvillain (1996) has shown that the root plays a role in French and that the manipulation of the frequency of the root has shown effects in derivational words. In the case for suffixed words, the root was integrated and accessed before the whole word was. Prefixed words did not show this pattern and the root showed frequency effects at a later stage in the word processing and so the whole word was processed before the root. Whole-word frequency effects were also found which gives rise to the conclusion that French words are simultaneously broken down into their root morphemes and are also accessed as a full unit (Beanvillain, 1996).

The dual role is also in effect in the Dutch language. Dutch nouns take on the -en ending in plural, which is an ending shared with verbs as well; studies have shown that highly frequent plural nouns are processed via the whole-word route while the low frequency ones are not (Baayen, Dijkstra, & Schreuder, 1997). The authors of that study suggest that this whole-word approach to frequent plural nouns is more efficient since it reduces the time cost of the -en ambiguous ending.

As for words based on derivational morphology, the decomposition of Dutch words into their morphemes seems to be an efficient process that happens in a left-to-right fashion where suffixes and prefixes yield different results (Bergman, Hodsonn, & Eling, 1988). The study also showed that the root extraction seemed to be automatic. Thus, the dual access route is evident in both derived and inflected Dutch words.

When it comes to English, the results are more mixed and rather outside the scope of this paper. It is possible that the nature of the language studies has a role to play here. English is half Germanic in origin, and this might set it apart from other Roman languages. Niswander et al. (2000) looked at the role of the root morpheme in derived and inflected English words. The results were the following: The frequency of the root had an effect on the processing of derived words in English, and the root is in some cases processed before the whole word is, though both play a role in lexical access. However, that effect was not always seen in inflected words.

It was seen in inflected words (with clear effects on fixation duration and gaze duration), but the case for verbs whose root is a noun was more complex to analyze. The effect of the frequency of the root had a spillover effect, and this can be seen as having a tangible rather than ephemeral effect on word processing. These results suggest that word processing can proceed along both the "direct access" and root based routes (Niswander et al., 2000).

Similar results have been seen with compound words. A compound word is a combination of 2 or more words that come together to form a new word such as school and child forming schoolchild. This is a common phenomenon in languages, such as English, German, and Finnish. They are especially common in the Finnish language and make up around 60% of the Finnish dictionary (Hyönä, Pollatsek, & Bertram, 2005). As reported by Hyönä et al. (2005), compound words are identified via the whole-word route (direct access) and the decomposition route (similar to root based route) operating in parallel. However, they did find a dominance of the decomposition route for long compounds, and the whole-word route for the short compounds as the latter would fall within the fixed word. As one fixation (Hyönä et al., 2005). In either case, the frequency of the first constituent influenced the first fixation duration and gaze duration on the compound word (Hyönä & Pollatsek, 1998).

As to compound words in English, while there is evidence for a priming effect via the constituents, there was no evidence to show that the meaning of the compound word is being accessed through any of its constituents (Pritson, Niswander-Klement, & Pollatsek, 2008). The compound words are accessed as a whole, as long as there is a lexical index for such a compound word (Pritson et al., 2008).

Morphology certainly plays a role in reading Hebrew (Deutsch et al., 2003), and this will be further discussed in the next chapter because of the linguistic similarity between Hebrew and Arabic. Morphology also plays a role in reading Chinese, with a stronger preview benefit coming from a character that shared the same morpheme as the target word than from one that was orthographically similar to the target word but represented another morpheme (Yen, Tsai, Tseng, & Hung, 2008).

Homographs (or Ambiguous Words)

Homographs are words that have more than one meaning. In eye movement literature, they are usually referred to as ambiguous words. These can be either balanced or biased; balanced, if both meanings are equally common, and biased if one is more common than the other.

When reading homographs, all possible meanings are momentarily accessed whether they are relevant to the sentence context or not; this is the case even in the presence of a strong bias in the context that preceded the ambiguous word (Swinney, 1979). This access is retained until 3 syllables after the ambiguous word at

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For a comprehensive review, refer to the text by Niswander, Pollatsek, and Rayner (2000).
Eye Movement Control: Where and When To Move the Eyes

Overview

Manipulations of the moving window paradigm and the delay of text onset have shown that fixation duration and saccade length vary independently of one another leading to the conclusion that the decisions of where and when to move the eyes are at least in part independent of one another (Rayner & Pollatsek, 1981). Other studies have also shown that the lengths of consecutive saccades do not correlate with one another; neither do the durations of successive fixations, or do fixation durations and saccade lengths correlate with each other (Rayner & McNicol, 1976). However, there are cases, such as at the end of a wrap-up clause, where higher-level cognitive processes are controlling both decisions of where and when to move the eyes; other examples include regressions and relaxations that are due to comprehension problems, and the skipping of high frequency or highly predictable words (Rayner, Kambh, & Dufy, 2000).

With regards to when to move the eyes, and as shown previously in this chapter, linguistic effects and cognitive processes seem to play a large role, and therefore it is very hard to argue for a reading model that does not account for these effects. The decision of when to move the eyes is in reality a question of the models of eye movement control in reading. Evidence, then, points to the conclusion that cognitive processes influence when to move the eyes (Rayner, 2009).

However, there are three competing theories: "minimal control, visual/oculomotor control, and cognitive control" (Rayner, Liversedge, White, & Verglin-Perez, 2003). Other researchers will simply recognize two schools of thought: one claiming that low level visual cues, text properties, and oculomotor system guide eye movement in reading, while the other claims that it is the ongoing cognitive processes that control eye movement in reading (Reichle et al., 2003). The latter seems a better...