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So Much to Read, So Little Time: How Do We Read, and Can Speed Reading Help?

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Summary
The prospect of speed reading—reading at an increased speed without any loss of comprehension—has undeniable appeal. Speed reading has been an intriguing concept for decades, at least since Evelyn Wood introduced her Reading Dynamics training program in 1959. It has recently increased in popularity, with speed-reading apps and technologies being introduced for smartphones and digital devices. The current article reviews what the scientific community knows about the reading process—a great deal—and discusses the implications of the research findings for potential students of speed-reading training programs or purchasers of speed-reading apps. The research shows that there is a trade-off between speed and accuracy. It is unlikely that readers will be able to double or triple their reading speeds (e.g., from around 250 to 500–750 words per minute) while still being able to understand the text as well as if they read at normal speed. If a thorough understanding of the text is not the reader's goal, then speed reading or skimming the text will allow the reader to get through it faster with moderate comprehension. The way to maintain high comprehension and get through text faster is to practice reading and to become a more skilled language user (e.g., through increased vocabulary). This is because language skill is at the heart of reading speed.

Keywords
reading, speed reading, eye movements, rapid serial visual presentation, word recognition, comprehension

Introduction

One day in 2007, six-time World Speed Reading Champion Anne Jones sat down in a popular bookstore on Charring Cross Road, London, and devoured the latest *Harry Potter* book in about 47 minutes (World Speed Reading Council, 2008). That worked out to a reading rate of over 4,200 words per minute (wpm). She then summarized the book for some British news sources. Another speed-reading enthusiast and promoter, Howard Berg, professes to be able to read as many as 30,000 wpm (World's Fastest Reader on Pelosi Bill, 2011). Reading rates of this kind seem extraordinary, given that college-educated adults who are considered good readers usually move along at about 200 to 400 wpm.

Given the immense volume of text available to us on a daily basis, it is unsurprising that most people would like to increase their reading rates to that of Jones or Berg. But is this possible? Some people suggest that it is: Proponents of speed-reading courses claim that we can dramatically increase our reading speed without sacrificing our understanding of the content by learning to take in more visual information at a single glance and by suppressing the inner speech that often occurs when we read silently. And now that text can be presented more dynamically, on digital devices as opposed to paper, there are claims that new methods of text presentation can allow us to read more quickly and with good understanding. The most popular of these technologies presents words rapidly one at a time on a computer screen using what is called *rapid serial visual presentation* (RSVP). The claim is that, freed from the need to move our eyes, we can read more quickly than we normally would. Other technologies manipulate the

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colors of presented lines of text, claiming that this can help us to reduce skipping or repetition of lines.

Is there a unique form of reading in which speed and comprehension are both high? Can we learn to read in this way through speed-reading courses, or can we achieve it with little or no practice by using special technologies? In this article, we address these questions. We begin by reviewing psychological research on normal reading and then discuss and evaluate methods that aim to increase reading speed. We adopt this approach because we believe that it is important to understand the visual and mental processes that occur in typical silent reading before determining whether special training or technologies can allow us to increase speed without sacrificing comprehension. Therefore, the first section of this article will review research on normal silent reading, focusing on those research findings that are most important for evaluating claims about speed reading. We will then consider the research on RSVP, the procedure that is used by some currently popular speed-reading technologies. With this background in place, we will evaluate speed-reading courses and technologies. As we will see, research shows that there is not a unique and easily learned behavior in which reading speed and comprehension are both high. There are effective ways of skimming a text to quickly find specific information, and skimming may suffice if complete and detailed comprehension of the text is not a priority. Reading can also be improved through practice. However, there is no quick and easy procedure that can allow us to read a text more quickly and still understand it to an equivalent level as careful reading. You will see why this is the case as we review what is known about normal reading.

Reading, Skimming, and Speed Reading

Before we embark on a discussion of research on normal reading and its implications for speed reading, we must provide a definition of reading. *Reading* is typically defined as the processing of textual information so as to recover the intended meaning of each word, phrase, and sentence. Of course, there are some forms of literature in which the author intentionally provides some level of ambiguity. For the most part, though, authors would like their readers to understand what they intend to communicate and to understand all of the words in the text. Often, the goal of reading is to learn something new, whether it is a fact from a textbook, a story from a novel, or instructions from a manual. Successful reading thus requires more than recognizing a sequence of individual words. It also requires understanding the relationships among them and making inferences about unstated entities that might be involved in the scenario being described.

Reading can be contrasted with *skimming*, in which the goal is to quickly move one's eyes through the text to find a specific word or piece of information or to get a general idea of the text content. As we will discuss later, skimming rates can be as much as two to four times faster than those of typical silent reading. Comprehension rates, however, are lower when skimming than when reading, suggesting a trade-off between speed and comprehension accuracy.

Where does speed reading fall on the reading–skimming spectrum? Our brief discussion of trade-offs between speed and comprehension suggests that a reader cannot "have his cake and eat it too," in the sense that comprehension must necessarily suffer if the reading process becomes more like skimming. Indeed, we will see there is little evidence for a unique behavior, such as speed reading, in which speed and comprehension are both high.

The Reading Process

To understand whether reading can be dramatically sped up while maintaining comprehension, it is important to understand how reading normally occurs. In this section, we review the visual and mental processes that are involved in silent reading when it proceeds as it typically does in educated adults, at a rate of about 200 to 400 wpm. Throughout the course of this discussion, it is important to keep in mind that reading is based on language; it is not a purely visual process. Speech is the primary form of language, and all human societies have a spoken language. (Groups of people who are deaf have developed languages that use the visual modality, but the primary languages employed by people with normal hearing all use the auditory modality.) We begin learning our spoken language as babies, and this process does not require explicit instruction. Reading and writing, which are relatively recent cultural inventions that are used in only some societies, normally require explicit instruction. That instruction begins around the age of 6 in many societies, although there are variations across cultures. It takes many years for a child to become a proficient reader. At first, children often read aloud, converting a printed text into the more familiar spoken form. Children gradually improve in their ability to read silently. Even in cultures in which reading is highly valued and widely taught, some children and adults never become good readers. These observations indicate that speech is the basic form of language; reading and writing is an "optional accessory that must be painstakingly bolted on" (Pinker, 1997, p. ix). Even though reading can be considered "an unnatural act" (Gough & Hillinger, 1980), many adults in modern societies perform this act quite skillfully. The body of research we now discuss has shed light on how they manage to do so.

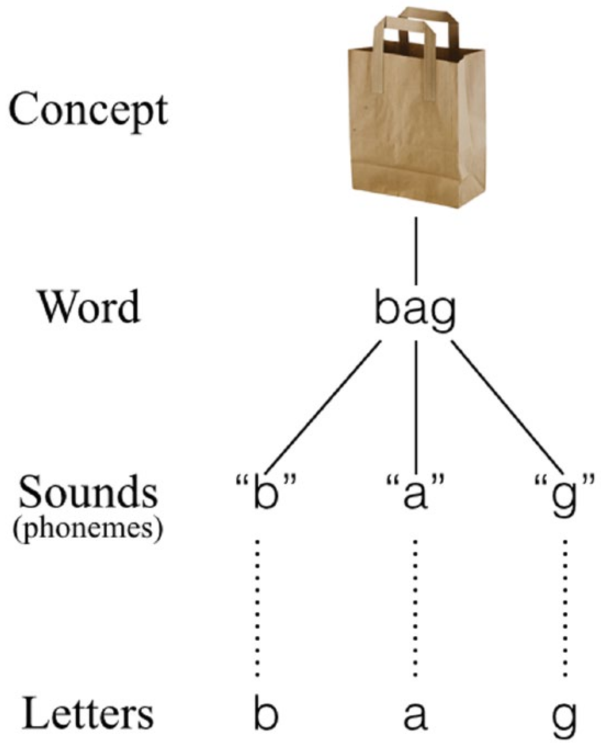

Fig 1. Diagram representing the orthographic (letter-based), phonological (sound-based), word, and conceptual representations of *bag*.

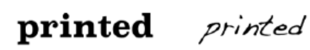

Fig. 2. The visual forms of the same word (*printed*) displayed in two different typefaces. Note that these two words appear to be physically different (e.g., thick, straight lines vs. thin, slanted lines) but are nonetheless recognizable as the same word form.

Writing systems

A logical starting point for reviewing the mental and visual processes involved in reading is to consider what the eye takes in and what the cognitive system must then process: the elements of writing system. Writing normally takes the form of visible marks on a surface, whether it is a clay tablet, a sheet of paper, a computer monitor, or another digital screen. In most languages, written words are composed of smaller visual units that can be combined in various ways. The basic written symbols of English and other alphabetic writing systems are letters, which approximately represent the sounds of the language, the *phonemes* (Fig. 1). For example, the word *bag* is represented by using a letter that represents the "b" sound, a letter that represents the "a" sound, and a letter that represents the "g" sound. The letters are arranged left to right along a horizontal line in the case of English, but other writing systems use other arrangements. For example, Hebrew arranges its symbols horizontally from right to left.

In some writing systems that are not alphabetic, the individual symbols that are arranged along a line represent units of meaning, *morphemes*, rather than units of sound. For example, the Chinese character 人 stands for "person." Some Chinese characters contain components that provide a hint about the character's pronunciation. However, these hints are not always present and, when present, are not always consistent or helpful. Most modern Chinese words contain more than one unit of meaning and must be expressed by a sequence of characters. For example, when the characters meaning "ground" (地) and "board" (板) are written together, they convey the meaning "floor" (地板). In Chinese, there are no spaces between any characters, so the only way a reader knows which two characters go together in a word is through experience. For the most part, however, this does not cause a problem for skilled readers.

The symbols of modern writing systems require no shading, no color other than that needed to distinguish the writing from the background, and no meaningful distinctions between lighter and darker lines or between wider and narrower lines. Once a symbol has been learned, it can be recognized in many printed forms. This use of abstract codes rather than visual templates (McConkie & Zola, 1979) helps to explain why we are able to recognize that a word has the same meaning regardless of the font or case in which it is printed (see Fig. 2). Despite the fact that letters are recognized by their abstract forms rather than visual templates, good visual acuity is required to pick up the critical differences between the marks that distinguish visually similar letters—for example, the difference between *h* and *n*. If this difference is not perceived, one could mistake *hot* for *not*.

Because discerning the correct visual form of words is an important precursor to the rest of the reading process, we now turn to a discussion of visual processing and the role of eye movements in reading before moving on to deeper aspects of the reading process: identifying words and understanding meaning.

Visual processing and eye movements

Given that writing is composed of fine lines and marks, the *acuity* (visual-resolution) limits of vision are an important constraint on the reading process. The premise behind some speed-reading courses is that it is possible to use peripheral vision to simultaneously read large segments of a page, perhaps even a whole page, instead of one word at a time (Brozo & Johns, 1986). However, such a process is not biologically or psychologically possible. One indication that it is not possible is that visual acuity

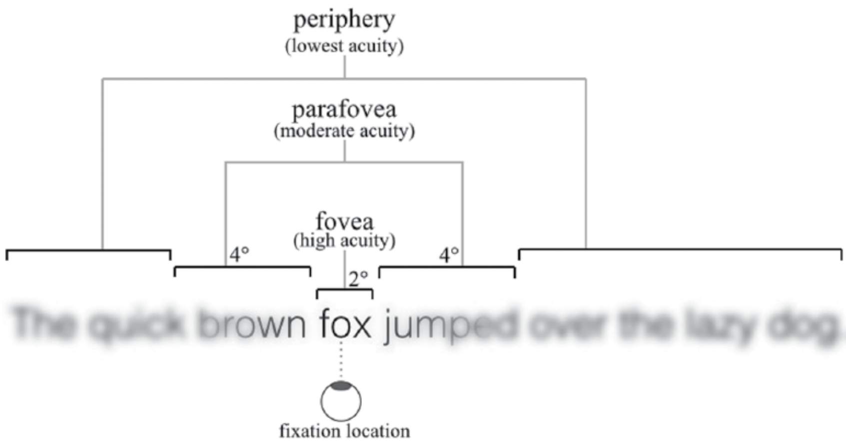

Fig. 3. Diagram illustrating visual acuity across the three regions of the visual field. Acuity decreases continuously as a function of distance from fixation location. The visual field consists of the fovea (center, with highest acuity), parafovea (middle region, with moderate acuity), and periphery (farthest region from fixation, with lowest acuity).

is limited and that these limitations are what cause readers to make eye movements. Acuity is much higher in the *fovea* (from the center of vision—the *fixation* location—to 1° of visual angle away from it in any direction) than in the *parafovea* (1°–5° away from the center of vision) or *periphery* (areas more than 5° away from the center of vision; Balota & Rayner, 1991; Fig. 3). To get a sense of how small the foveal viewing area is, note that it is roughly equivalent to the width of your thumb held at arm's length from your eye.

Saccades (quick, ballistic eye movements) allow readers to move the fovea to the word they wish to process with the highest efficiency. Therefore, the *oculomotor* (eye movement) system controls the sequence and timing of the visual system's access to the text. Decisions about how long to fixate a word and when to move the eyes to the next word are to a large extent under the control of cognitive processes (Rayner, Liversedge, White, & Vergilino-Perez, 2003; Reingold, Reichle, Glaholt, & Sheridan, 2012; see Rayner & Reingold, 2015). They are not preprogrammed before one begins to read a text in the way that a metronome is set by a musician before he or she begins to practice a piece of music. This moment-by-moment control helps to ensure that the next word enters the system through foveal (high-resolution) vision with the optimal timing. In the following sections, we detail how the visual and oculomotor systems support and constrain the reading process.

The visual system. As mentioned, acuity is highest in the fovea, and this is the area in which the majority of word recognition occurs. One reason that acuity is higher in the fovea than in other areas of the visual field is related to the distribution of two types of neural receptors that respond to light—*rods* and *cones*. Cones are sensitive to color and detail and are more effective in bright light, while rods are sensitive only to brightness (e.g., shades of gray) and motion and are mostly sensitive (i.e., useful) in dimly lit rooms or at night. Cones are concentrated in the fovea and decrease in density with increasing distance from fixation. Rods are least concentrated in the fovea and increase in density with increasing distance from fixation (Fig. 4). Because cones are more sensitive to detail, this means that acuity is higher in the fovea, where there are more cones, than in nonfoveal areas.

Another reason why acuity is higher in the fovea than in other areas of the visual field has to do with the way information is transmitted from rods and cones (located in the *retina*—a membrane lining the back of the inside of the eyeball) to the brain. Information from rods is *pooled* (averaged across a group of rods) before being relayed to the brain, while information from individual cones is relayed directly, without being combined with information from other cones (Fig. 5). The consequence of this organization is that even minute variations in the

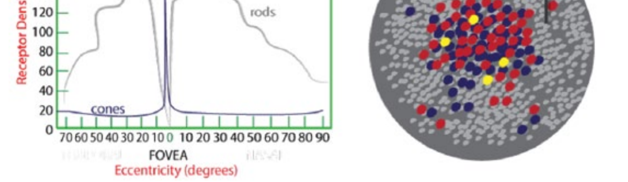

Fig. 4. Diagrams showing the distribution of rods and cones across the visual field (left panel) and retina (right panel).

pattern of light hitting the fovea will be preserved by the cones. If one cone receives bright light and an adjacent cone receives very dim light, the brain will perceive a light/dark boundary. In contrast, minute variations in the pattern of light hitting nonfoveal areas (where cones are sparse and there are mostly rods) will be obscured. If one rod receives bright light and an adjacent rod receives very dim light, the brain will perceive a gray blob.

These facts about rods and cones have some important implications for reading. As we have discussed, all text, regardless of writing system, is composed of combinations of lines, normally dark on a white background. Therefore, fine discrimination between dark and light areas is essential to recognizing the visual elements of writing. If the light pattern coming from a word hits the fovea, the cones will easily recognize such fine detail and relay the pattern—with high fidelity—to the brain. However, if the word hits nonfoveal areas and is sensed primarily by rods, it will be relayed to the brain as an average and will appear fuzzy. This will make it difficult to discern the exact identities of the symbols (see the beginning and the end of the sentence represented in Fig. 3). In fact, when people are asked to report the identity of a word that is presented so briefly that they cannot make an eye movement, accuracy is high in the fovea but drops off dramatically outside of it, with performance reaching chance level around the middle of the parafovea (approximately 3° of visual angle away from fixation; Bouma, 1973; see also Bouma, 1978; Rayner & Morrison, 1981). These facts cast doubt on suggestions from speed-reading proponents that people can read more effectively by using peripheral vision, taking in an entire line or even an entire page at a time.

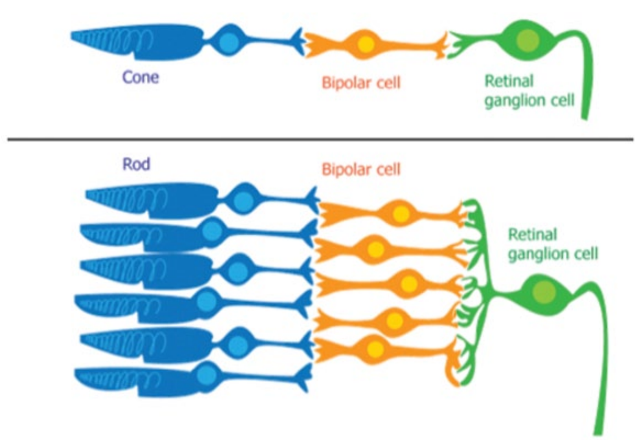

Fig. 5. Diagram showing how information is relayed from the retina to the brain. Information from cones (top panel) is relayed directly through bipolar cells to ganglion cells and onward to the brain, whereas information from rods (bottom panel) is pooled (averaged) through bipolar cells and ganglion cells.

Eye movements. For over a century, researchers have been monitoring eye movements in order to study the cognitive processes underlying reading. The technology has evolved over the years so that eye tracking can now be achieved with a high-speed video camera connected to a computer and can be used to study readers of any age. In general, these technologies work by computing the location of the eye up to one thousand times per second, allowing the researcher to know, with precision to the millisecond, which word and where in the word the reader is looking at a particular time. This information can then be separated into times when the eyes remain in the same location (i.e., during fixations) and times when they move between locations (i.e., during saccades). In this section, we review what has been discovered in studies of experienced adult readers, generally college students, who are reading silently in their first language.

As mentioned earlier, the reason readers make saccades is to move their fovea to the next word. The eyes are relatively stable during fixations, which last approximately 250 ms for experienced adult readers. In general, no new visual information is obtained during saccades (Matin, 1974), but cognitive processing continues during this time (Irwin, 1998). This is important, because some speed-reading technology developers have claimed that saccades waste time. However, because cognitive processing continues during saccades, this time is not wasted. We can conclude, however, that fixations are the reader's opportunity to obtain new visual information from the text. Although the average fixation lasts about 250 ms, there is considerable variability in how long an individual fixation lasts. These variations reflect such things as the legibility of the text (e.g., light/dark contrast, filled-in or removed spaces between words), linguistic difficulty (e.g., word frequency, predictability, ambiguity), properties of the reader (e.g., age or reading skill), and task goals (e.g., reading, proofreading, skimming).

One reason fixations last as long as they do is that eye movements are motor responses that require time to plan and execute. For example, even in the simple task of moving the eyes to a new stimulus that appears either to the left or to the right of the eye's current location, the reaction time is in the range of 100 to 1,000 ms, depending on the stimuli and experimental conditions (see Gilchrist, 2011). The reaction time in reading is in the shorter end of this range, 150 to 200 ms, because the eyes generally move in one direction (Becker & Jürgens, 1979; Rayner, Slowiaczek, Clifton, & Bertera, 1983). Additionally, a number of processes are being conducted at once: Processing of the fixated word, planning to move the eyes forward, and processing of the upcoming word using parafoveal information all overlap in time. This means that saccade latencies in reading can be shorter than in simple saccadic reaction-time tasks because some

of the cognitive processing that leads to the decision of when to move the eyes can occur before the fixation on a particular word even begins.

On average, forward saccades when reading English last about 20 to 35 ms and span the distance of 7 letters. Saccade durations, like fixation durations, are variable. But the variation is mostly determined by the distance traveled rather than by the cognitive and linguistic variables that affect fixation durations (Rayner, 1998, 2009). Saccades usually move from one word to the next word. However, about 30% of the time, readers move past the next word to the following one. These *skips* are more likely to happen when the word is very short, extremely frequent, and/or highly predictable from the prior context. The word *the* has these characteristics, and it is skipped about 50% of the time or more (see Angele & Rayner, 2013). Importantly, just because a word is skipped does not mean that it was not processed at all. All major theories of reading posit that word skipping is based on at least partial recognition of the word from information obtained in parafoveal vision and/or expectations about the word's identity. In fact, if readers are given passages to read in which words that most people skip over are omitted, comprehension suffers rather dramatically (Fisher & Shebilske, 1985). This shows that readers are actually processing many or most of the words they skip over, along with the words they fixate. It also suggests that every reader is unique in terms of the timing and sequence of words he or she needs to directly look at in order to read efficiently. What works for some people, such as the initial readers in Fisher and Shebilske's study, who were able to choose which words they fixated, does not work for others, such as the readers who got the modified text. The implication is that speed-reading devices that control the timing of word presentation may not be ready to use "out of the box" but instead may need to be tailored to each individual user based on how that person would naturally process the text.

Not all saccades move forward to the next word in the text (Fig. 6). A small proportion of eye movements result in *refixations* on the same word. Refixations are most common for long words, about 7 or more letters long in English, for which the end part of the word may not fall within the word-identification span (described below). About 10% to 15% of the time, skilled readers make *regressions*, moving backward in the text to a previous word. Regressions are different from *return sweeps*—eye movements that go from the end of one line of text to the beginning of the next. Although return sweeps and regressions are both right-to-left movements in writing systems that go from left to right, such as English, return sweeps continue to move forward with respect to the progression of the text, whereas regressions move backward.

Because return sweeps tend to be long saccades, there is some error in where they land, sometimes requiring an additional fixation to correct (Just & Carpenter, 1980). In general, though, these corrective saccades take half the time that normal saccades take and do not disrupt the reading process too much (in fact, readers almost never notice them). Some color-based technologies for presenting text have recently been developed that aim to make it easier to make return sweeps. However, as we will discuss in more detail later, return sweeps and other aspects of oculomotor control are generally not the difficult part of reading. Faulty language processing generally causes problems in eye movement programming, not the other way around.

Regressions are more important than return sweeps with respect to understanding reading because they constitute a deviation of the reader's eye movements from the normal progression of the text. Although some regressions are made to correct for oculomotor error (e.g., the eye's landing too far past the intended word), many regressions are made to correct a failure in comprehension (e.g., when the reader has misinterpreted the sentence). This is important in the context of speed-reading technologies that use RSVP because these technologies do not allow people to reread the text to correct misunderstandings in an intelligent way that is informed by the reader's understanding of the text. Given that most backward eye movements are made in order to repair a failure in comprehension, readers would maintain misinterpretations if they forced

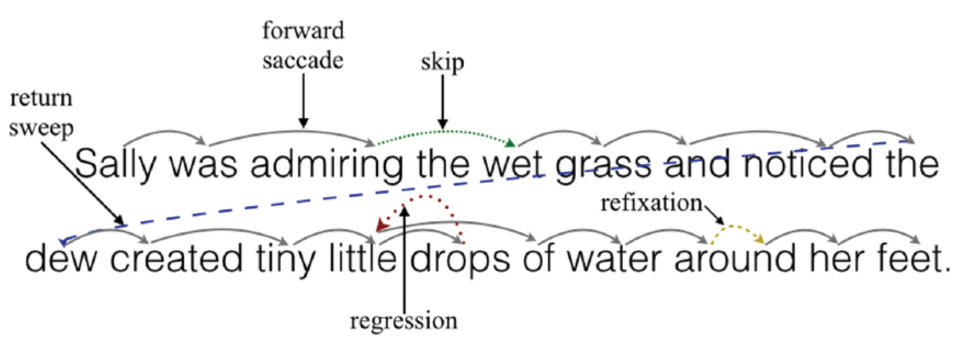

Fig. 6. Schematic diagram of eye movements during reading.

themselves to keep moving forward and would comprehend the text less well (Schotter, Tran, & Rayner, 2014).

The use of foveal and parafoveal information to process text. Now that we have reviewed the characteristics of eye movements, we return to the issue of how information is obtained from a text once an eye movement is made. Visual perception occurs very rapidly—so rapidly, in fact, that even if a word disappears completely after being directly looked at for only 60 ms, reading behavior is unaffected. That is, fixation durations have been shown to be similar regardless of whether the word remains visible or is erased or masked after 60 ms (Ishida & Ikeda, 1989), and in both cases, the durations continue to be sensitive to linguistic properties of the fixated word (e.g., how common it is; Rayner et al., 2003). These findings suggest that visual perception takes up only a small fraction of fixation durations, leaving time for higher-level cognitive and linguistic processing to occur before the decision of when to move the eyes next. Crucially, the finding that readers' eyes remained on words that had disappeared for as long as they would have if the words had still been there suggests that the reading system naturally delays looking directly at the next word until it has performed a certain amount of linguistic processing of the currently fixated word. Therefore, devices that present words faster than readers' natural pace may run the risk of presenting a word before the brain is prepared to process and understand it.

Although acuity is lower in the parafovea than in the fovea, information in the parafovea is not completely ignored. If the word to the right of the fixated word disappears after 60 ms, reading behavior is disrupted (even if the word reappears once it is directly fixated; Rayner, Liversedge, & White, 2006). This finding suggests that readers use information from more than just the fixated word in order to read efficiently. This is important in light of speed-reading technologies that present just one word at a time: They do not allow the opportunity to use information from the next word.

A different way to determine how much is seen in a single fixation is to examine eye fixations when readers can see clearly only a limited window of text that moves as the eyes move, using the *gaze-contingent moving-window paradigm* (McConkie & Rayner, 1975; see Rayner, 2014, for a review). In this paradigm, the reader's fixation location is monitored and the text is manipulated based on the position of the eye (Fig. 7). The letters immediately surrounding the center of fixation are revealed, forming a window of clear text. Each of the letters outside the window, in some studies including the spaces, is replaced with an *x*. On different trials, the window may be small (e.g., as small as a single letter) or large (e.g., 40 letters). The experimenter measures reading rate as a function of window size. The general finding is that reading rate increases as the window size increases until it reaches an asymptote, the point at which reading rate is equivalent to that with a completely visible line. The window size at the asymptote point represents the size of the reader's *perceptual span*. In general, in English the size of the perceptual span is 3 to 4 letter spaces to the left of fixation (McConkie & Rayner, 1976; Rayner, Well, & Pollatsek, 1980) and 14 to 15 letter spaces to the right of fixation (McConkie & Rayner, 1975; Rayner & Bertera, 1979).

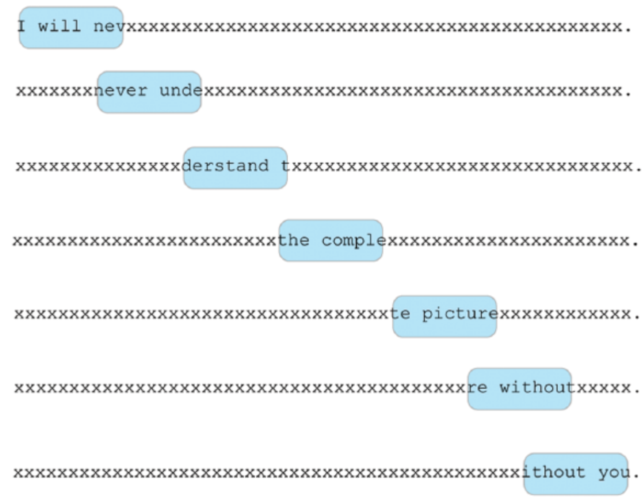

Fig. 7. Diagram of the moving-window paradigm with a 9-character window. From top to bottom, the lines show successive displays of an example sentence. The centers of the blue rectangles represent the locations of fixations, and the size of the rectangles reflects the size of the window.

The perceptual span is determined not by physical space or the distance traveled by the eyes but rather by the amount of linguistic information that can be obtained from the text. This fact is demonstrated in several ways. First, the distance the eyes move during a saccade is equivalent (when measured in terms of number of letters), regardless of the distance from the reader or size of the text (Morrison & Rayner, 1981). Second, across languages, there are differences in the size and shape of the perceptual span. In Chinese, it is 1 character to the left and 3 to the right (Inhoff & Liu, 1998), and it is larger to the left than to the right in both Hebrew (Pollatsek, Bolozky, Well, & Rayner, 1981) and Arabic (Jordan et al., 2014). These differences reflect differences in the languages and writing systems. The perceptual span in Chinese is smaller than in English because words are shorter in Chinese (mostly 2 characters) than in English (on average, about 5 letters). The size of the perceptual span in the two languages is equivalent when measured in number of words instead of number of characters, suggesting that there may be a generally optimal rate of uptake of linguistic information that is more or

less consistent across languages. The asymmetry of the perceptual span is reversed in Hebrew and Arabic compared to English because Hebrew and Arabic are read right to left and English is read left to right—the perceptual span is larger in the direction of reading compared to where the reader has already been. Third, the asymmetry of the perceptual span switches toward the direction of the eye movement when readers make regressions (Apel, Henderson, & Ferreira, 2012). Thus, the size of the perceptual span is not a physical limitation; otherwise, it would not change with reading direction. Rather, the perceptual span reflects constraints on how linguistic information from the text is obtained and used to recognize and understand words.

Further evidence that the perceptual span is limited by cognitive and linguistic factors rather than just by acuity comes from a study that used a clever manipulation to compensate for the drop-off in acuity that occurs in the parafovea (Miellet, O'Donnell, & Sereno, 2009). This *parafoveal magnification technique* is similar to the moving-window technique. However, instead of text being masked outside the center of vision, it is magnified as a function of distance from fixation (Fig. 8). On every fixation, parafoveal and peripheral letters should have been perceivable to the same degree as foveal letters because of the magnification. It turned out that this manipulation did not increase the size of the perceptual span. If our ability to obtain useful information from the text were limited solely by visual acuity, increasing the visibility of eccentric letters would have allowed them to be perceived better and would have increased the size of the perceptual span. The results of the study suggest that the perceptual span is limited by our ability to identify and process the meaning of the words in the text.

When a word falls within the perceptual span, it can be perceived but not necessarily fully identified. In fact, the area from which words can be identified, the *word-identification span*, is much smaller than the perceptual span. The word-identification span is about 7 characters to the right of fixation in English (see Rayner, 1998). Thus, with normal text, there is a small window comprising the currently fixated word and one or two words to the right within which words are identified. The perceptual span is a larger window, used to perceive the visual layout of the text (i.e., where the words and spaces are, in writing systems that use spaces) in order to plan eye movements. The final aspect of the perceptual span that we should point out is that readers do not access any information from the lines above or below the line currently being read (Pollatsek, Raney, LaGasse, & Rayner, 1993). This is important because it is inconsistent with the speed-reading claim that someone can read an entire page at once. The findings about the perceptual span suggest that, contrary to the claims of speed-reading

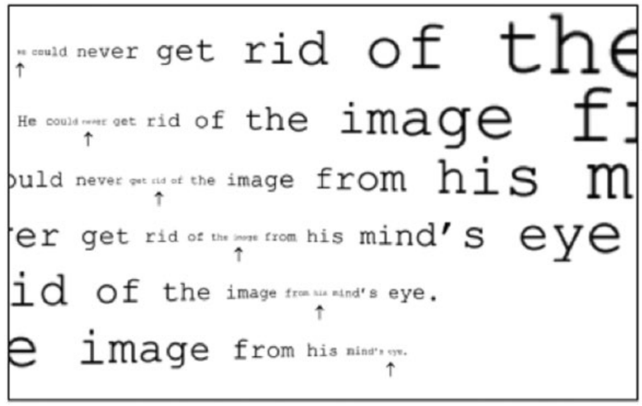

Fig. 8. Depiction of the parafoveal-magnification paradigm. The location of each fixation is indicated with an arrow, and the corresponding display for that fixation is represented. Consecutive lines represent the chronological order of fixations. Reprinted from "Parafoveal Magnification: Visual Acuity Does Not Modulate the Perceptual Span in Reading," by S. Miellet, P. J. O'Donnell, and S. C. Sereno, 2009, *Psychological Science, 20*, p. 722. Copyright 2009 by the Association for Psychological Science. Reprinted with permission.

courses, readers cannot obtain information from a very large area of the visual field but rather primarily process text in the center of vision (i.e., the fovea).

Further support for this idea comes from a study that used the *moving-mask paradigm* (Rayner & Bertera, 1979). This technique is similar to the moving-window technique except that the mask (i.e., the string of *x*s that replaces the letters in the text) moves in synchrony with the eyes, obscuring the text in foveal vision instead of nonfoveal vision. In this study, readers were extremely disrupted when even a single letter in the fovea was masked—their reading rates dropped by half and continued to drop precipitously as the size of the mask increased. Therefore, readers were not able to read effectively by relying on parafoveal and peripheral vision alone.

Although research using the moving-window paradigm provides us with an assessment of how much of the text readers can perceive on a given fixation, it tells us little about what type of information is obtained from words before they are fixated and how this information is used in reading. To investigate this, researchers have used the *boundary paradigm* (Rayner, 1975). Here, people read sentences in which a specific word is manipulated. Initially, it is replaced with a different word (or nonword) called the *preview*. As illustrated in Figure 9, there is an invisible boundary located just prior to this preview word, which, when crossed by the reader's gaze, causes the preview to change to the *target* word—the word that makes sense in the sentence. Readers are rarely aware that words are changing because the change occurs during a saccade when vision is suppressed (Matin, 1974). However, the change may be noticeable if

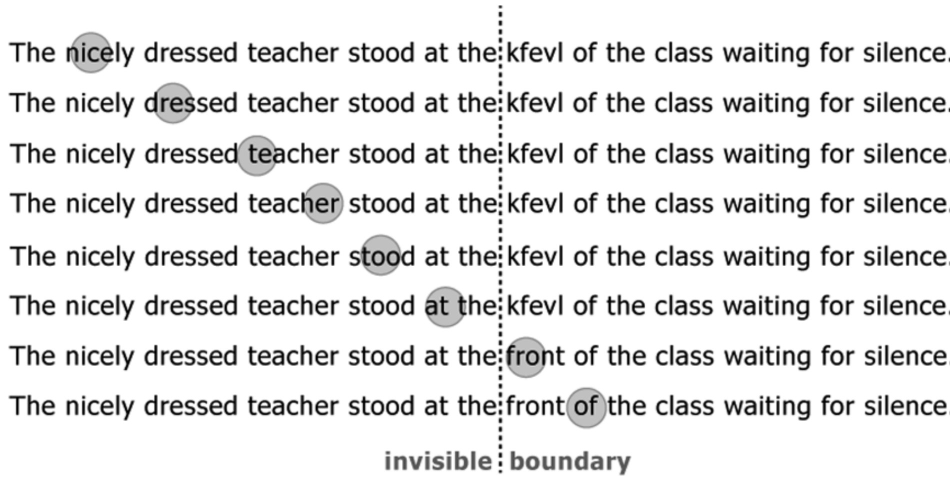

Fig. 9. Diagram of the boundary paradigm. The vertical dashed line represents the location of the boundary, which is invisible in the experiment. When the reader's gaze (represented by gray circles) crosses this location, between the third-to-last and second-to-last lines, the preview word ("kfevl," in this example) changes to the target word ("front").

it is visually drastic (e.g., if an ascending letter such as *h* changes to a descending letter such as *y*) or if the eyes were very close to the preview word before the boundary was crossed (Slattery, Angele, & Rayner, 2011).

The general finding from studies using the boundary paradigm is that readers obtain *parafoveal preview benefit*. That is, they are faster to read the target when the preview was identical to the target than when the preview differed from the target (for a review, see Schotter, Angele, & Rayner, 2012). The boundary paradigm allows researchers to manipulate the nature of the relationship between the preview and target in order to gain more detailed information about exactly what type of information causes the preview benefit. We turn now to studies that have addressed this issue, which is important in the context of speed-reading technologies that present one word at a time and do not allow for parafoveal preview.

Readers obtain something more abstract from the input than pure visual features. This was cleverly demonstrated by McConkie and Zola (1979), who had readers learn to read something like "AlTeRnAtInG cAsE" and then either changed the case of each of the letters (making the text read "aLtErNaTiNg CaSe") or left the letters unchanged during a saccade. Changing the case of the letters did not affect fixation durations at all, suggesting that readers had discarded the exact visual form of the letters and that their reading behavior was based on abstract letter codes (i.e., the identity of the letters; see also Friedman, 1980; Rayner, McConkie, & Zola, 1980; Slattery et al., 2011). But beyond the identity of letters, there is abundant evidence that readers are faster to read a target word when the preview was phonologically related to it. This holds true for readers of alphabetic writing systems such as English (Pollatsek, Lesch, Morris, & Rayner, 1992) and French (Sparrow & Miellet, 2002) as well as non-alphabetic systems such as Chinese (Pollatsek, Tan, & Rayner, 2000). Although initial evidence suggested that preview benefit does not reflect processing of word meaning (Rayner, Balota, & Pollatsek, 1986; Rayner, Schotter, & Drieghe, 2014), more recent evidence indicates that some aspects of the upcoming word's meaning are processed under certain conditions (Hohenstein & Kliegl, 2014; Rayner & Schotter, 2014; Schotter, 2013; Schotter, Lee, Reiderman, & Rayner, 2015).

Finally, research using the boundary paradigm has demonstrated that readers typically do not obtain information from the second word to the right of the fixated word (e.g., Angele & Rayner, 2011; Rayner, Juhasz, & Brown, 2007) unless the two words following the fixated word are short (i.e., close to the fovea), common, and/or predictable (Cutter, Drieghe, & Liversedge, 2014; Radach, Inhoff, Glover, & Vorstius, 2013). If observed, preview benefits from the second word to the right of the fixated word are typically smaller in magnitude than preview benefits from the word immediately following the fixated word.

The findings from both the moving-window paradigm and the boundary paradigm are quite consistent with the research we discussed earlier regarding the limitations on reading and the fact that people need to move their eyes so as to place the fovea over the region that they want to process. That is, they suggest that people need to move their eyes to look at words directly in order to read efficiently. These findings do not align with some of the central claims of speed-reading courses, such as that readers can obtain information from a large area of text

in a single fixation. Nor do they align with the claims of some speed-reading technologies, such as that reading will be more efficient if words are presented one at a time, without the opportunity for parafoveal preview.

Reading speed across people. Is there variability in reading speed? Unsurprisingly, reading speed varies greatly among individuals (Rayner, 1998; see Table 1), most notably as a function of reading skill: Fast readers make shorter fixations, longer saccades, and fewer regressions than slow readers (Everatt & Underwood, 1994; G. Underwood, Hubbard, & Wilkinson, 1990; see Everatt, Bradshaw, & Hibbard, 1998). Importantly, in a study that examined a large number of cognitive skills, the factor that most strongly determined reading speed was word-identification ability (Kuperman & Van Dyke, 2011). This finding suggests that reading speed is intimately tied to language-processing abilities rather than eye movement–control abilities.

Models of eye movement control. While we have learned a great deal about eye movements and reading over the past few decades, there are still some open questions. However, the research that has been done so far has provided such a detailed understanding that researchers have been able to develop sophisticated models of eye movements during reading. These models are computer programs that do a very good job of predicting how long readers will look at words and where they will move their eyes next. There are a number of such models (see Reichle, Rayner, & Pollatsek, 2003), but two have received the most attention: the E-Z Reader model (Reichle, Pollatsek, Fisher, & Rayner, 1998) and the SWIFT model (Engbert, Nuthmann, Richter, & Kliegl, 2005). Although a full discussion of these models is beyond the scope of the present article, the most important point for present purposes is that, in the models, word identification is a primary determiner of when and where readers move their eyes. We do not set an unchanging pace and length for eye movements in advance of reading a text. Rather, we vary our pace and our movements depending on our ongoing cognitive processes: how well we are processing the incoming information. A second important point is that, in adapting such models to account for the development of reading skill in children, the parameters that need to be modified are those associated with language-processing ability rather than those that specify eye movement–control ability (Reichle et al., 2013). This finding from the modeling work further supports the idea that language processing, rather than the ability to control the movements of one's eyes, is the primary driver of reading performance. Given this, we now turn to an overview of one major aspect of language processing: word recognition, and its role in reading.

Word recognition

Reading obviously consists of more than recognizing individual words. But, given that a writing system represents the words of a language, words are the basic stepping-stones to reading and comprehension. You cannot reasonably expect to understand a text if you do not know what the words mean (imagine trying to read an unfamiliar language). In this section, we detail what is known about word recognition.

One of the biggest influences on the time that it takes to recognize a word is its *frequency* of occurrence—essentially, how often the word has been encountered before (Rayner, 1998, 2009). In reading, as in listening,

Table 1. Mean Fixation Duration, Mean Saccade Length, Percentage of Regressions, and Reading Rate for 10 Skilled Readers (Rayner, 1998)

Reader	Fixation duration (ms)	Saccade length (characters)	Regressions (%)	Reading rate (words per minute)
K. B.	195	9.0	6	378
J. C.	227	7.6	12	251
A. K.	190	8.6	11	348
T. P.	196	9.5	15	382
T. T.	255	7.7	19	244
G. T.	206	7.9	4	332
G. B.	205	8.5	6	347
B. B.	247	6.7	1	257
L. C.	193	8.3	20	314
J. J.	241	7.2	14	230
Mean	216	8.1	11	308

Note: Adapted from "Eye Movements in Reading and Information Processing: 20 Years of Research," by K. Rayner, 1998, *Psychological Bulletin, 124*, p. 393. Copyright 1998 by the American Psychological Association. Adapted with permission.

words that are more common (e.g., *house*) require less time to recognize than words that are less common (e.g., *abode*). The effects of word frequency can be thought of as operating through practice or experience; the more times you have encountered and recognized a word, the easier it will be for you to do it again in the future.

The word-frequency effect can be demonstrated for written words seen in isolation by measuring reaction time in tasks such as the *lexical decision task* (Stanners, Jastrzembski, & Westbrook, 1975), the *naming task* (Berry, 1971; Forster & Chambers, 1973), and the *categorization task* (Van Orden, 1987). These tasks are depicted in Figure 10. In a lexical decision task, words and nonwords are briefly presented on a computer screen and the participant's goal is to determine whether each letter string is a word or not. In a naming task, the goal is to read the word aloud as quickly and as accurately as possible. In the categorization task, the goal is to determine whether the word is a member of a certain semantic category—for example, the category of foods. For words embedded in passages of text, the frequency effect can be measured by examining eye fixation times during silent reading (Rayner & Duffy, 1986) or *event-related brain potentials* (*ERPs*; King & Kutas, 1998) during the reading of words presented one at a time via RSVP. During silent reading and RSVP, the participant's goal is to understand the sentence in order to recall the text or to answer comprehension questions about it. Despite these differences in the requirements or goals of the tasks (e.g., determining word status, accessing pronunciation, or accessing meaning), the frequency effect is apparent across all of them (although the magnitude of the effect changes depending on the task; Schotter, Bicknell, Howard, Levy, & Rayner, 2014). Thus, it is a ubiquitous and robust influence on the word-recognition process.

From letters to words. Recognizing a word, in an alphabetic writing system, involves processing the letters within it. As we discussed earlier, the letters in the words of alphabetic writing systems symbolize the sounds that are used to pronounce the word, and the pronunciation is in turn associated with a meaning. We now turn to the question of how people recognize the individual letters within the word and retrieve the pronunciation and meaning.

For most words, including short and medium-sized ones, all of the letters within the word are recognized simultaneously. For very long words such as *antidisestablishmentarianism*, it may not be possible to recognize all the letters simultaneously (recall that the size of the word-identification span is only about 7 letters to the right of eye fixation in English). These words require multiple fixations in order to be recognized. Simultaneous recognition of letters is more efficient within words that are well known than words that are completely new to the reader. In fact, it is actually easier to recognize a letter inside a known word than it is to identify it in isolation! This effect, termed the *word-superiority effect*, was discovered over 125 years ago by Cattell (1886) and later confirmed with more rigorous methods by Reicher (1969) and Wheeler (1970). Experiments demonstrating this effect have used the general design that is shown in Figure 11.

A person sees either a word (e.g., "word"), a nonword with the same letters in a jumbled order (e.g., "orwd"), or a single letter (e.g., "d") presented very briefly on a computer screen—so briefly that there is not enough time to make an eye movement. Next, a mask stimulus (e.g., "####") replaces the initial stimulus, barring the person from holding onto the information about the word, nonword, or letter in any type of raw visual form. The person is cued to a particular position in the stimulus (e.g., the last

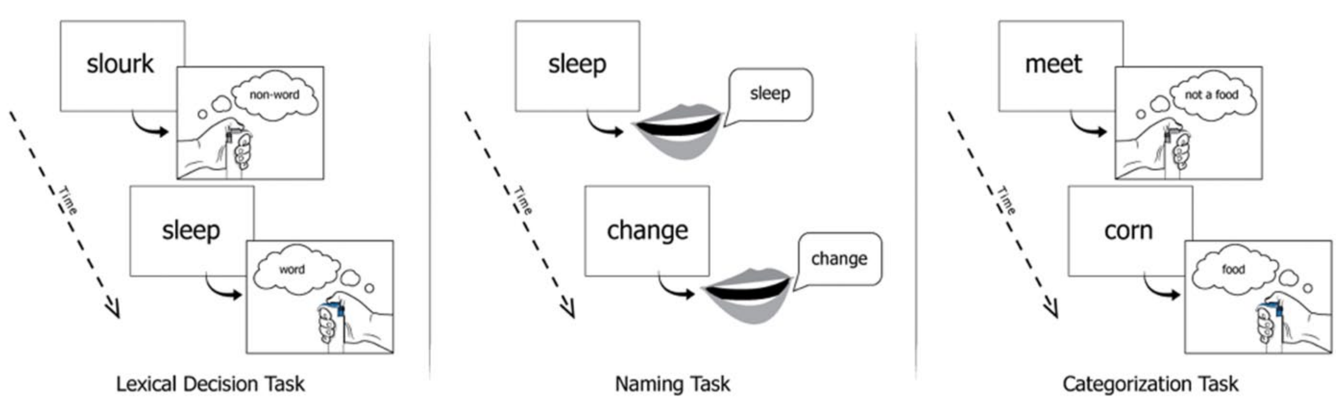

Fig. 10. Diagram of three tasks commonly used to study word reading. For the lexical decision task, in which the goal is to decide if the letter string is a word or nonword, the top panel shows a nonword trial and the bottom panel shows a word trial. For the naming task, the goal is to read aloud the word. For the categorization task, in which the goal is to decide if the word fits into a given category (e.g., "foods"), the top panel shows an item that fits the category and the bottom panel shows an item that does not.

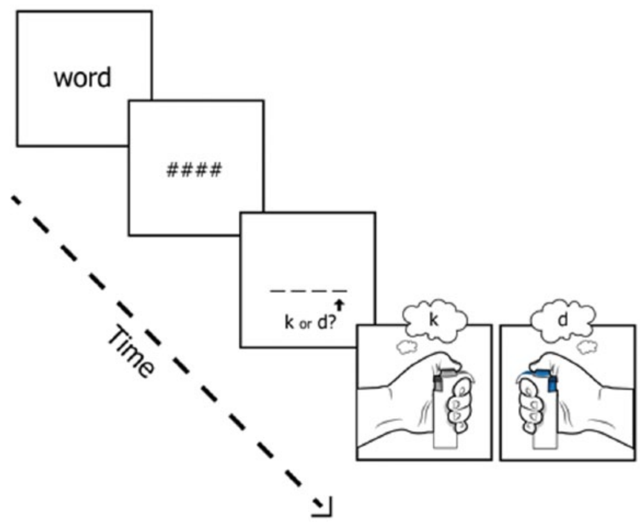

Fig. 11. Diagram of the paradigm used by Cattell (1886), Reicher (1969), and Wheeler (1970) to demonstrate the word-superiority effect. From top to bottom, the first three panels show successive displays in the experiment. The pair of panels at the bottom show the participant's potential responses.

position) and asked to report which of two possible letters had been presented at that location (e.g., "d" or "k"). Note that in this example (and for all the items in Reicher's and Wheeler's experiments), either of the response options in the word condition would make a real word (i.e., either *word* or *work*). This means that using knowledge about what letters would make the letter string form a word in English could not help a person perform above the level of chance, which is 50%. But performance in the word condition is much better than chance and much better than in either the nonword condition or (quite surprisingly!) the isolated-letter condition.

Even more impressive than the word-superiority effect is the fact that, once established, the word-recognition system is so efficient that it can interfere with processes that seem to be very basic, such as color recognition. The clearest demonstration of this is the *Stroop effect*, named after the scientist who discovered it (Stroop, 1935) and replicated hundreds of times since (see MacLeod, 1991, for a review). This effect is so robust that it can be demonstrated easily in classrooms with a single piece of paper and a timer.

In the Stroop task, the goal is to name the color of the ink in which each word is printed as fast and as accurately as possible—you can try it yourself by using Figure 12. Start with the first column and time yourself. Then try the second column, and then try the third. You may notice that each column feels more difficult than the last and takes you more time. This is because when the word names a color that is different from the color you are trying to say, as in the third column, you have difficulty selecting the correct response. You do not experience such competition in the first column (because the word and ink color lead to the same response) or in the second column (because the string of *x*'s does not bring a particular word to mind).

What is so surprising about this effect, besides how robust and easily demonstrated it is, is that we would generally think that color naming should be so easy that the words should be irrelevant—recall that the cones (photoreceptors in your eye) are specifically tuned to detect color. In fact, some recently developed speed-reading apps that use color claim "Ever wonder why stop lights use color and not words? It's because the human brain processes color very quickly—much more quickly than it can process words" (http://www.beelinereader.com/). The Stroop effect suggests that it might not be as simple as that; once a reader is proficient in a language (this effect does not appear when the words are printed in a language the person does not know), word recognition is so incredibly quick and strong that it can interfere with retrieval of a competing word—the name of the color.

The optimal viewing position effect. It is important to note that, with the Stroop effect, the interference created by a mismatch between the word name and the ink color is strongest when people are looking at the center of the word than when they are fixating more peripheral

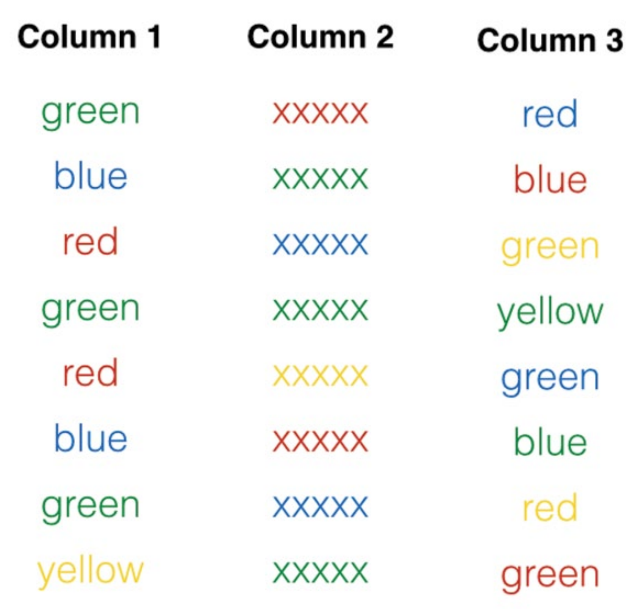

Fig. 12. Example stimuli in the Stroop paradigm. The task is to name the color of the ink that the word is printed in as quickly and accurately as possible. Column 1 shows stimuli in the congruent condition (each word names the color in which it is printed), Column 2 shows stimuli in the neutral condition (each stimulus is a colored string of *x*'s), and Column 3 shows stimuli in the incongruent condition (the words name colors different from the colors they are printed in).

letters (Perret & Ducrot, 2010). This is important because of another robustly demonstrated effect—the *optimal viewing position* (OVP) effect—in which words that are presented in isolation are recognized more efficiently when people are looking in the center of the word than when they are looking at more external letters (O'Regan, Lévy-Schoen, Pynte, & Brugaillère, 1984). Although this effect is consistently obtained for single-word presentations, it is small, on the order of only a few milliseconds. It is even smaller during natural reading of text (Vitu, O'Regan, & Mittau, 1990), probably because of the ability to obtain parafoveal preview that we discussed earlier. This will become an important point later when we talk about some recent speed-reading technologies that present words centered near the OVP. The claim is that this is done because people cannot recognize a word until they fixate the OVP. The research shows, however, that people are not incapable of recognizing words if they do not fixate the OVP; instead, the recognition process is just slightly slowed.

The role of phonology in silent reading. Given that all writing systems represent words and given that the primary form of language is vocal and auditory, not visual, it is no surprise that phonological processing plays an important role in reading—even in silent reading (see Leinenger, 2014). This is true not only for alphabetic writing systems, in which letters represent the individual phonemes in words, but also for non-alphabetic writing systems such as Chinese. We will now describe a number of studies showing that readers naturally access the sounds of words while reading silently and that attempts to inhibit this process generally have negative effects on reading. These studies are important to examine in light of the speed-reading claim that use of inner speech causes problems for readers.

First, consider a study in which skilled readers were asked to indicate (with a button press) whether briefly presented words were members of a certain category (e.g., foods; Van Orden, 1987). The people in this study incorrectly responded "yes" to a word that was not a member of the category (e.g., *meet* for the category food) about 19% of the time if that word was a *homophone* of a true member of the category: In this example, *meet* is pronounced the same as *meat*, which is a food. Incorrect "yes" responses to non-homophone words—for example, *melt*—occurred only 3% of the time. This is because while *melt* shares the same number of letters with *meat* as *meet* does, it does not share the pronunciation. When people did correctly respond that, for example, *meet* is not a food, it took them longer to do so than it did for *melt*. These results suggest that people accessed the sounds of the word and were strongly influenced by the fact that its phonological code was identical to that of an actual member of the category. Readers of Chinese also activate the sounds of words when they read (Xu, Pollatsek, & Potter, 1999), although Chinese is not an alphabetic writing system.

Studies using homophones have also found evidence for inner speech during silent reading of text. For example, when people were asked to read silently and make very quick judgments about whether sentences made sense, they incorrectly accepted a sentence like "She has blonde hare" about 12% of the time, more often than they incorrectly accepted a sentence like "She has blonde harm" (about 5% of the time; Treiman, Freyd, & Baron, 1983). If use of phonology were an unimportant process that readers could easily turn off, we would have expected them to do so. The fact that they could not suggests that phonology is fundamental to the process of reading.

What would happen if we eliminated inner speech during reading? It is difficult to design a procedure that prevents people from performing a mental activity, but researchers have tried two approaches. One approach is to use biofeedback techniques to get people to reduce the activity that sometimes occurs in their speech muscles while they are reading silently. In one study, a tone was played when a monitor picked up such activity and readers were instructed to keep the tone off (Hardyck & Petrinovich, 1970). Readers were able to keep the tone off to some extent, and their performance on a later comprehension test was unaffected if the text was easy but was impaired if the text was more difficult. This effect did not just seem to reflect the added complexity of reading while listening for a tone, because comprehension did not suffer in a group of participants whose arm muscle activity was monitored in a similar way.

Another way to try to decrease the use of inner speech during silent reading is to have people count aloud or repeat an irrelevant word or phrase while they are reading (Daneman & Newson, 1992). In such studies, readers showed poorer comprehension of passages when they repeated the irrelevant words, but not when they repeated an irrelevant sequence of taps with their fingers. This latter result suggests that it was speech, rather than the requirement to perform two tasks, that impaired reading comprehension. In another study in which people repeated irrelevant speech while reading silently, readers were quite good at answering comprehension questions about individual concepts but were worse at answering questions that required them to combine concepts and make inferences (Slowiaczek & Clifton, 1980). These findings support the idea that, when it comes to understanding complex materials, inner speech is not a nuisance activity that must be eliminated, as many speed-reading proponents suggest. Rather, translating visual information into phonological form, a basic form of language, helps readers to understand it.

Word-recognition models. Earlier, we discussed how researchers have developed detailed models of eye movement control. There are also detailed models of the word-recognition process. The models that have received the most attention and motivated the most research are the *dual-route cascaded* (DRC) model (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) and *parallel distributed processing* (PDP) models, also called *connectionist* or *triangle* models (e.g., Seidenberg & McClelland, 1989). The models disagree on some points, showing that scientists still have things to learn about the process of recognizing words. However, there are some important areas of agreement. For one, the models share the basic assumption that bottom-up orthographic input interacts with what people know about words to produce pronunciations and meanings. That is, both detailed visual information from the text and prior experience with the language are necessary. Another area of agreement between models of word recognition is that internal representations of phonology play a role in the recognition of words that are presented visually and not pronounced aloud by the reader.

The role of context in selecting the correct word meaning. In some cases, a word has two separate meanings but the same spelling and the same pronunciation. An example of such a *homograph* is *bank*, which can refer to a financial institution or the side of a river. Lexical ambiguity of this sort complicates word recognition. Lexical ambiguity is not rare—the English language contains over 1,500 homographs (Leinenger & Rayner, 2013)—and it may even be a desirable feature of language because it allows us to reuse word forms for multiple purposes instead of creating new, increasingly large and complex words (Piantadosi, Tily, & Gibson, 2012). Still, difficulty arises because merely knowing the word's visual form and pronunciation does not indicate which of the two meanings the reader should interpret.

When a homograph is encountered in isolation, it is impossible to discern its intended meaning. Luckily, readers usually have the benefit of a sentence context that can give them clues as to which meaning they should interpret. For example, it would be easy to infer that *bank* means "financial institution" when it is preceded by "John went to deposit some money at the . . ." In contrast, you might be more likely to infer that it means "side of a river" if it were preceded by "John went to sail a boat at the river . . ." In this example, the information that helps distinguish the meaning of *bank* comes before the word itself. But sometimes the disambiguating information appears after the word. In these situations, readers are less likely to make the correct initial interpretation. Rather, readers tend to make regressions back to the word if they had initially misinterpreted it (e.g., Duffy, Morris, & Rayner, 1988; Rayner & Duffy, 1986).

Difficulty or uncertainty discerning exact word meaning can also arise when word forms are visually very similar, as with orthographic-substitution neighbors (e.g., *birch* and *birth*) and transposition-letter neighbors (e.g., *calm* and *clam*). The likelihood that the word will be misinterpreted is higher if the correct word is rare and the highly similar word is more common. Context can help readers in such cases; readers have an easier time recognizing the correct word (as opposed to the visually similar word) when the preceding sentence context indicates the correct meaning (Johnson, 2009; Slattery, 2009).

Sentence context also helps readers with words that are neither homographs nor neighbors of another word, indicating that the effect is fairly general. For example, a constraining context, one that makes a particular word predictable, leads to that word's being fixated less often (i.e., skipped more) and for less time than if it were preceded by a neutral context that could be completed by a wide range of words (Ehrlich & Rayner, 1981; Zola, 1984; see Rayner, 1998, 2009, for reviews). A constraining context also speeds response time in naming (Stanovich & West, 1979, 1981; West & Stanovich, 1982) and lexical decision tasks (Schuberth & Eimas, 1977) and affects the brain's response to words as measured with ERPs (Kutas & Hillyard, 1984; see Kutas & Federmeier, 2011). The findings about the importance of context in visual word recognition suggest that training courses that teach students not to reread and speed-reading devices that do not allow for going back will make readers more likely to misinterpret words when they occur in less constraining contexts.

Comprehension

Given that reading typically progresses rather smoothly, we may not notice the subtle complexities that are associated with understanding the meaning of a text. We have already mentioned that some words are ambiguous because they have multiple meanings. Sentences also can be ambiguous in that it is not always obvious how each individual word in a given sentence functions and relates to the other words (i.e., the sentence's *syntax*). Consider the sentence "While Mary was mending the sock fell off her lap." When reading a sentence like this, readers often initially misinterpret it (the term for this is *getting garden pathed*; see Frazier & Rayner, 1982; Rayner, Carlson, & Frazier, 1983). This happens because readers, like listeners, tend to process words incrementally, as soon as they have identified them. They often assume at first that "the sock" is the object of "was mending" (i.e., that what Mary was mending was the sock). Of course, after reading the end of the sentence, it is clear that that interpretation

could not possibly be correct (if so, then what fell off her lap?). In reality, the sentence should be interpreted such that "the sock fell off her lap" is a sentence unit (a *constituent*) and that Mary was mending something that was not stated in the text. When we introduce this idea and these types of sentences to students in the classroom, they often note that ambiguity could be avoided if the writer simply put a comma after "was mending" to disambiguate the sentence by separating the two constituents. One might argue that good copy editors would not let such a sentence occur and that such poorly written sentences should be rare. However, the comma is indeed optional in English grammar and writers (and speakers) are not very good at anticipating whether readers (or listeners) are likely to misinterpret what they write (or say; Ferreira & Schotter, 2013). Therefore, garden-path sentences like this occur much more often than one might imagine (they are quite notorious for occurring in newspaper headlines; e.g., "McDonald's fries the holy grail for potato farmers": Crash Blossoms Up the Garden Path, 2009).

Further complicating the process of understanding sentences is that words can be ambiguous with respect to their grammatical role—that is, their part of speech. In the garden-path example we have been discussing, the problem in interpreting the sentence is not due to difficulty discerning the meaning of the individual words but rather to difficulty deciding whether Mary was mending the sock or whether the sock fell. Add to that ambiguity the difficulty of deciding whether a word itself means one idea or another and you find yourself in a very difficult situation. For example, consider a sentence that begins, "The desert trains . . ." With only these words, you will not be able to figure out how this phrase should be interpreted until you get more information from the rest of the sentence. Context would help you determine whether those words should be interpreted as a noun and verb (i.e., "The desert trains boys to be men") or an adjective and a noun (i.e., "The desert trains are hot and dusty"). The information that would help you understand the roles and meanings of "desert trains" occurs after the ambiguous phrase. When you first encounter the words "desert trains," you must make a best guess as to how to understand them. When your first guess at an interpretation is wrong, then you run into problems. In these situations, readers fix the problem by making regressions and rereading the sentence (or parts thereof) in order to find the correct interpretation (Frazier & Rayner, 1987).

Fixing comprehension failure. The examples we have been discussing show that discourse can sometimes contain syntactic ambiguities and it is only via careful reading that the reader will be able to appreciate the appropriate meaning. Readers are often able to fix comprehension problems by rereading—something that speed-reading training courses discourage and that devices using RSVP may make impossible. In fact, recent research demonstrates this point quite clearly. Schotter, Tran, and Rayner (2014) had people read garden-path sentences (such as the one in Fig. 13) while their eye movements were monitored. The sentences were presented either normally or with a *trailing-mask* manipulation, in which each letter in a word was replaced with an *x* after the reader's eyes moved past it. This manipulation ensured that readers had only one encounter with the word—if they returned to reread it, they would be looking at a string of *x*'s. Schotter and colleagues found that readers could accurately respond to a two-alternative comprehension question about the sentence much better when they were able to reread words (i.e., when they made a regression in the normal reading condition: 75% accuracy) than when they could not (i.e., when they made a regression in the trailing-mask condition: around 50% accuracy—chance performance). These findings suggest that having only one encounter with the words in the sentence might not be sufficient for successful understanding of the text.

During silent reading, the eyes slow down slightly at the ends of sentences or phrases (Just & Carpenter, 1980; Warren, White, & Reichle, 2009). However, this does not mean that all comprehension occurs there. Readers have already understood most of the words and sentence meaning by that point. Evidence for this idea comes from the fact that people make occasional regressions to reread prior parts of a sentence and that these regressions are not triggered only from the punctuation mark at the end of the sentence; rather, they can be triggered from various parts of the sentence (von der Malsburg & Vasishth, 2013). This finding suggests that readers noticed a failure in comprehension partway through reading a sentence. Some wrap-up comprehension processes do occur at the ends of phrases or sentences (Just & Carpenter, 1980), but much language processing occurs as the individual words come in.

Comprehension of passages of text. So far, we have talked about comprehension primarily at the level of individual words and sentences. But readers must also build an ongoing mental model of the entire text, integrating information across sentences (e.g., Zwaan & Radvansky, 1998). They must not only understand each sentence, which requires short-term memory, but also retain the information in longer-term memory. Sometimes readers make very long regressions—for example, from the end of a paragraph to the beginning—in order to make sense of the current discourse's reference to something that was stated earlier. The important point here is

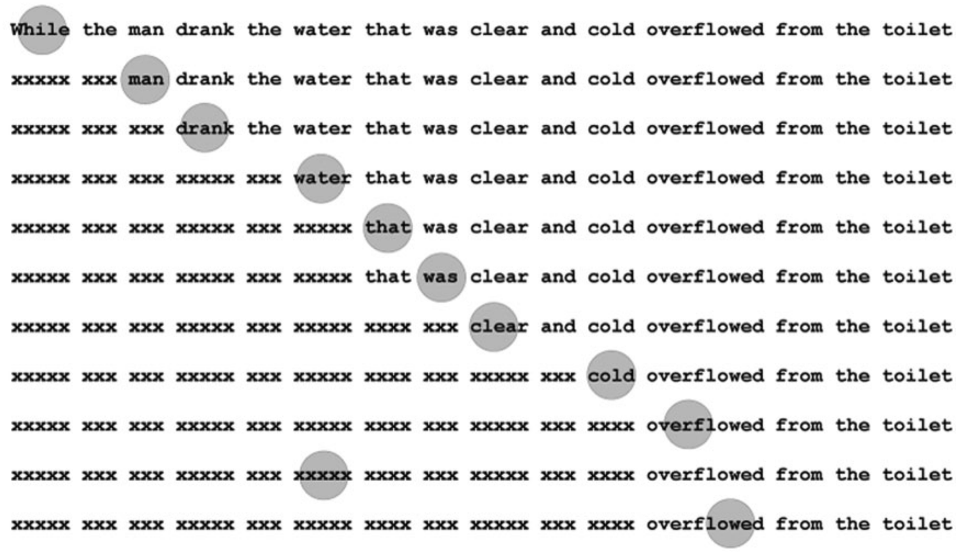

Fig. 13. Diagram of the trailing-mask paradigm (Schotter, Tran, & Rayner, 2014). From top to bottom, the lines show successive displays of an example sentence. Gray circles represent the locations of fixations. Once a reader made a forward saccade out of a word, each of its letters was replaced with an *x* for the remainder of the trial, even if the reader looked back to it, as shown in the second-to-last line.

that one advantage the reading of normal text has over methods that force the eyes to move straight down a page or present words one at a time is this opportunity—the opportunity to move backward in the text in order to recover information that was initially missed or forgotten.

Measuring comprehension. It is fairly easy to measure reading rate by computing the number of words read in a set period of time (e.g., wpm). It is harder to measure comprehension. Given that speed-reading courses and devices promise to increase speed without decreasing comprehension, the question of how comprehension should be measured is critical to discuss.

Most often, researchers measure comprehension with multiple-choice questions that are presented after a sentence or a paragraph that probe the reader's memory for it. The advantage of this method is that it is fairly easy to get a score for comprehension. However, the test is only as good as the questions and the incorrect answers that are provided as foils for the correct answer. In some cases, it is possible for people who never read the text to do surprisingly well on the test (although they would probably have a hard time doing better than someone who read the text carefully). Furthermore, there is evidence that reading behavior changes depending on the type of questions included on a comprehension test (Radach, Huestegge, & Reilly, 2008; Wotschack & Kliegl, 2013), suggesting that readers may adopt different strategies for reading in anticipation of what they need to retain from it.

An alternative to multiple-choice questions are tests requiring some open-ended response, such as asking readers to give a summary of what was just read. This type of test may provide a better estimate of comprehension, but this method is not without its pitfalls. Scoring open-ended summaries is much more subjective than scoring multiple-choice questions, and comprehension scores for the same response can vary drastically depending on who scores it, how rigorous the coding scheme was, and so on. Although some variability in response scoring can be eliminated by using a consistent scorer, such as a computer program, we are still a long way from creating a computer program with a native-like grasp on all the nuances of natural language.

Participants in speed-reading courses are often evaluated for comprehension both before and after the course, not for research purposes but to show participants how their reading has changed. Prior to beginning a speed-reading program, students are typically given a *pretest* that measures both their reading speed and comprehension. At the end of the training program, they are given a *posttest*. Sometimes the pretest is harder than the posttest, and other times trainees are tested repeatedly on the same material (Carver, 1971, 1972). In both cases, it is inevitable that their performance will be better on the posttest merely because of the relative difficulty of the tests or because of repeated exposure. In other cases, training programs change the measurement used to assess reading between pre- and posttest. A new student in a speed-reading course generally has his or her reading speed measured in a straightforward way (e.g., wpm). However,

after the course, what is often measured is the *Reading Efficiency Index* (RE Index; Carver, 1990), based on the argument that rapid reading rates should be qualified by the percentage of the material that the reader is able to comprehend. To calculate this measure, the reading rate is multiplied by the percentage of correct responses on the comprehension test. Thus, if a reader had a reading rate of 5,000 wpm and scored 60% on the comprehension test, his or her RE Index would be 3,000 wpm (5,000 × 0.60). Since comprehension was not factored into the measurement of the pretest assessment, trying to infer what type of improvement the course caused relies on comparing apples and oranges. For example, if a multiple-choice test with four questions is used, people who "read" at 5,000 wpm and understood absolutely nothing (i.e., answered the comprehension questions at the level of chance—25%) would get an RE Index score of 1,250 wpm. But if they did not understand anything about the text, can we really say that they were reading?

Conclusions about the natural reading process

We have seen that reading is an elegantly choreographed dance among a number of visual and mental processes. Modern research has shown that, contrary to some earlier views (Goodman, 1967), reading is not a psycholinguistic guessing game in which we guess the identities of words and other linguistic units based on minimal visual input. Rather, we pick up detailed visual information from the text, moving our eyes so that we fixate most words once and going backward to reread if problems arise. The visual information that we obtain, combined with our knowledge of the language we are reading, allows us to identify the words in the text and to comprehend it.

Reading silently is faster for skilled readers than either reading aloud or hearing someone else read the text. This difference reflects, in part, limitations on how quickly we can talk. A speaking rate of 150 to 160 wpm is comfortable; this is the rate that is recommended for speakers who are recording audiobooks or podcasts. Those who have practiced rapid speaking, such as auctioneers, can maintain rates close to that of skilled reading, between 250 and 400 wpm. Some people prefer to double the speed of audio books to get through them more quickly, but this still brings the speed up only to the middle of the average reading-rate range (i.e., around 300 wpm). Viewed in this light, most people reading this article are already going quite quickly. Yet in the modern world, with its abundance of text, people often want to go even quicker. Is there a special form of silent reading in which speed and accuracy are both high? Even better, is there a form that we can use effectively without having to spend time on training and practice? We turn now to a review of research on reading via RSVP, in which words are presented rapidly one at a time. This presentation technique is used in some speed-reading technologies that claim to be able to produce rapid reading with preserved comprehension and without the need for much, if any, practice. It is important, therefore, to find out what research shows about reading via RSVP.

Rapid Serial Visual Presentation

Presenting text with the RSVP method allows a reader to maintain fixation at a single location on a display as a sequence of words is presented in quick succession. The execution of eye movements is not required at all. The RSVP method was originally used as a tool to scientifically study reading-comprehension processes (e.g., Forster, 1970; Forster & Ryder, 1971; Holmes & Forster, 1972; Potter, 1984). As we will see, subsequent investigations have provided a rich body of information about how reading is altered by this special method, information that is important for evaluating speed-reading technologies that use it.

Reading single sentences with RSVP

In research using RSVP, a short series of words is presented, with each word in view for about 100 ms (i.e., at a speed of about 600 wpm; this duration varies across studies). Then the participant is asked to recall the words. Strikingly, when the words form a meaningful sentence, participants are quite good at this task. When the words are unrelated or scrambled, however, performance is poor (Potter, Kroll, & Harris, 1980). The fact that a reader can easily understand and remember a single RSVP sentence shows that words can be recognized and the meaning of a sentence can be understood very rapidly. Success with a single sentence might be attributed to readers' holding words in memory until the end of the sentence and then assembling them into meaningful propositions after the rapid presentation has ended (Mitchell, 1979, 1984). That is, the words may have been presented at a faster rate than the comprehension system could follow. However, there is evidence that sentence comprehension can occur even during the course of RSVP presentation of single sentences. For example, Masson (1986) presented sentences via RSVP at 100 ms per word (equivalent to 10 words per second or 600 wpm). The sentences were constructed so that the final word appeared in uppercase letters and remained on the screen until the reader made a response to it (in one experiment, readers made a lexical decision; in another, they named the word aloud). For some sentences, the final word was highly predictable from the preceding sentence context (e.g., "He mailed the letter without a STAMP"), and in other

sentences, the final word was unrelated to the meaning of the sentence (e.g., "He mailed the letter without a DRILL"). Masson found that readers were able to identify the final word more quickly when the sentence context made it predictable, both when the readers were making lexical decisions about the words and when they were naming them aloud. Importantly, the effects of predictability were substantial for both tasks, although somewhat less than those reported in earlier studies in which, instead of RSVP, people read the sentences at a normal rate and then made the lexical decision or naming response (Fischler & Bloom, 1979; Stanovich & West, 1983).

To show that the RSVP predictability effects were truly due to successful sentence comprehension, Masson included a condition in his study in which sentence contexts were scrambled (e.g., "the without letter a mailed He STAMP"). Predictability effects were much weaker for the scrambled sentences than for the normal sentences, indicating that sentence comprehension contributed to those effects. Overall, these results showed that participants could understand RSVP sentences as they were presented at the rate of 10 words per second, even when the task required them to attend only to the final uppercase word.

Masson's (1986) study showed effects of sentence context on reading of the final word of an RSVP sentence, but such effects can also be observed for words that appear in the middle of the sentence. In a study by Potter, Moryadas, Abrams, and Noel (1993; see also Potter, Stiefbold, & Moryadas, 1998), participants read sentences such as "The sailor washed the dack of that vessel" presented via RSVP at 10 words per second. Each sentence included either a nonword ("dack", which is meaningless in English) or a real word ("duck", which made no sense in the sentence) that looked similar to an appropriate word ("deck"). Readers were instructed to view the RSVP stream and then write down exactly what they had seen, including unexpected words and misspelled words. Despite this warning, people misreported the nonword ("dack") as "deck" 40% of the time and the inappropriate word ("duck") as "deck" 26% of the time. These and other similar results indicate that a largely unconscious process combines letter-level information and the sentence context in order to identify words, with a bias toward actual words and toward words that are plausible in context. The effect of context on these errors suggests that readers were processing the meaning of the sentence even though they were reading at more than twice the normal rate.

Reading more than single sentences with RSVP

Although RSVP readers can successfully read individual sentences, this does not necessarily mean that they can comprehend longer texts. With something like a newspaper article or a book chapter, readers must not only understand individual sentences but also build an ongoing mental model of the entire text. Do RSVP readers comprehend and remember what they have read as well as readers of normal text?

Two studies of text comprehension using RSVP indicated that this method led to comprehension equivalent to that of normal reading when total presentation time was equal to that of normal reading. When the RSVP stream was sped up, however, comprehension and memory suffered. In one study, participants read short paragraphs that were difficult to make sense of without a title and then recalled them (Potter et al., 1980). One such paragraph (adapted from Bransford & Johnson, 1972) was as follows:

> The procedure is quite simple. First you arrange everything into different groups. One pile may be enough if you don't have much to do. Then you have to go somewhere else if you do not have a machine. You put them into the machine and turn it on. It is better not to put too many in at once. Then you sit and wait. You have to stay there in case anything goes wrong. Then you put everything in another machine and watch it go around. When it stops, you take the things home and arrange them again. Then they can be put away in their usual places. Soon they will all be used again and you have to do it all over. [Doing your laundry/The whole thing] can be a pain.

One group of participants read these paragraphs via RSVP at one of three rates equivalent to 200, 400, or 600 wpm; another group read the paragraphs on printed pages for equivalent durations of time per paragraph. The key information was presented at the beginning, middle, or end of the paragraph or was omitted (in this example, both the phrase presenting key information and the alternative phrase with that information omitted are shown in brackets). All readers had a much easier time understanding and recalling the passage when the topic was mentioned in the first sentence than when it was mentioned only in the last sentence or not at all, showing that they were using the information to comprehend the subsequent sentences. At all rates, including 600 wpm, over 80% of the RSVP readers recalled the key topic word (laundry, in this example) when it was present anywhere in the paragraph, but few guessed it when it was omitted. Nonetheless, detailed recall accuracy dropped markedly as the rate of presentation increased.

For participants who read the paragraphs in normal printed form, recall was high for the first half of the paragraph but dropped markedly for the second half when

the allotted reading duration was equivalent to that for the higher RSVP rates, because participants could not finish reading the entire paragraph. These readers recalled the topic word when it was presented in the first sentence but often omitted it when it was presented in the middle or at the end. Thus, while average accuracy was similar for normal reading and RSVP when the text was presented at about 200 wpm (a normal to slow reading rate for skilled readers), what the readers were able to remember was somewhat different between the two forms of presentation: At higher rates, a crucial word was more likely to be missed by normal readers than RSVP readers.

Juola, Ward, and McNamara (1982) carried out a similar study and found similar comprehension scores between normal reading and RSVP when overall wpm was equated. However, as in Potter et al.'s (1980) study, performance dropped by about 50% when the rate was increased, either by speeding up the RSVP stream or giving readers less time with the paragraphs. Overall, the results suggest that if you have a limited time to read something, RSVP may be a good way to see the text without missing anything. However, the time saved will be at the cost of relatively poor comprehension and memory.

In both of the studies we have been discussing (Juola et al., 1982; Potter et al., 1980), a brief pause was inserted between each sentence. This would have allowed comprehension processes to catch up to some extent with the rapid presentation of the text stream. As we mentioned earlier, studies of eye movements in normal reading show that readers typically pause briefly at the end of sentences. Masson (1983) showed that without these pauses, comprehension success was reduced in the RSVP condition relative to a condition in which people skimmed passages presented in full view for the same duration.

In summary, although immediate comprehension may be successful with single sentences presented using RSVP speeds well beyond typical reading rates, scaling up to full text passages yields substantial comprehension costs. As discussed earlier, comprehension is usually assessed through the ability to recall or answer questions about text, which relies on the text's being encoded into long-term memory. This encoding appears to be particularly compromised by speed-reading procedures, including RSVP (Masson, 1986).

Increasing Reading Speed and Maintaining Comprehension: Proposals and Evaluations

Now that we have reviewed the scientific evidence on normal reading and reading with RSVP, we are in a position to look in detail at the claims of speech-reading courses and technologies and to consider whether these claims are valid. In the sections that follow, we ask whether these methods can fulfill the promise to dramatically increase reading speed without hurting comprehension. In addition, we review other potential methods to help readers get through an enormous amount of text efficiently: effective skimming and practice.

Speed-reading courses

Speed reading was launched into public popularity in the United States with the introduction of the Evelyn Wood Reading Dynamics program in 1959. Evelyn Wood was a high school teacher who claimed that she could read very fast with good comprehension by grasping whole phrases in a single glance. Together with her husband, she formed a company to teach speed reading via this method. Very quickly the number of franchises throughout the United States grew. Wood and her husband eventually sold the company, but the basic principles that she advocated still form the foundations of most current speed-reading training courses. These courses attempt to teach students to change certain aspects of the reading process while maintaining the same input method, such as a book or computer display.

Increasing the perceptual span. Advocates of training courses make a number of assumptions about how silent reading occurs and how speed can be increased without sacrificing comprehension. Central to these claims is the idea that our brain is rather lazy and that we effectively process much less than we are actually capable of. A specific claim is that readers have the ability take in much more information in a single glance than they normally do and that training can "unlock" this ability. For example, in two-thirds of a sample of 40 books on speed-reading methods reviewed by Brozo and Johns (1986), the claim is made that a reader's span of recognition can be improved with practice. Most of the books also strongly advocated against making regressive eye movements while reading. A survey of a sample of more recent publications that we undertook revealed that they contained similar ideas, including recommendations to use peripheral vision to expand the number of words that can be read in a single fixation and to reduce regressive eye movements. The argument is that, after training, speed readers can process entire groups of words and phrases in a single fixation. At the extreme, it is claimed that speed readers can zigzag down one page and up the other page, processing the information in the text much more efficiently than normal skilled readers do.

The evidence that we have reviewed on normal reading challenges these claims. First, what limits our ability to process text is our capacity to recognize words and

understand text (e.g., Miellet et al., 2009). It is highly unlikely that we can increase this ability by learning to make eye movements differently. Second, processing words out of order from the sensible sequence of the sentence (Masson, 1986) or when some of the words are removed (Fisher & Shebilske, 1985)—as would happen when a speed reader uses a zigzag movement—impairs the ability to process and understand the words. Third, regressive eye movements actually support comprehension (Schotter, Tran, & Rayner, 2014) rather than causing a problem for reading. Together, these facts about reading suggest that the ability to read is limited by our ability to attend to, identify, and understand words rather than our ability to see them. Even if our vision could be improved, we would not necessarily read faster. This conclusion is consistent with the finding that attempts to train readers to use peripheral vision more effectively with simple perceptual tasks that flash words in the periphery have not been successful in allowing them to read more quickly with good comprehension (Brim, 1968; Sailor & Ball, 1975).

Suppressing the inner voice. Another claim that underlies speed-reading courses is that, through training, speed readers can increase reading efficiency by inhibiting *subvocalization*. This is the speech that we often hear in our heads when we read. This inner speech is an abbreviated form of speech that is not heard by others and that may not involve overt movements of the mouth but that is, nevertheless, experienced by the reader. Speed-reading proponents claim that this inner voice is a habit that carries over from fact that we learn to read out loud before we start reading silently and that inner speech is a drag on reading speed. Many of the speed-reading books we surveyed recommended the elimination of inner speech as a means for speeding comprehension (e.g., Cole, 2009; Konstant, 2010; Sutz, 2009). Speed-reading proponents are generally not very specific about what they mean when they suggest eliminating inner speech (according to one advocate, "at some point you have to dispense with sound if you want to be a speed reader"; Sutz, 2009, p. 11), but the idea seems to be that we should be able to read via a purely visual mode and that speech processes will slow us down.

However, research on normal reading challenges this claim that the use of inner speech in silent reading is a bad habit. As we discussed earlier, there is evidence that inner speech plays an important role in word identification and comprehension during silent reading (see Leinenger, 2014). Attempts to eliminate inner speech have been shown to result in impairments in comprehension when texts are reasonably difficult and require readers to make inferences (Daneman & Newson, 1992; Hardyck & Petrinovich, 1970; Slowiaczek & Clifton, 1980). Even people reading sentences via RSVP at 720 wpm appear to generate sound-based representations of the words (Petrick, 1981).

Evaluations of trained speed readers. Although the results of the studies we have reviewed suggest that the claims of speed-reading courses are overstated, it could be argued that data from people who read at typical speeds cannot be generalized to speed readers. Perhaps speed readers are doing something very different from typical readers. Indeed, studies of extraordinary performers in other cognitive domains have hinted at this idea. For example, the average person is capable of remembering only about 7 items (e.g., random digits, letters, words) in their presented order; larger sequences lead to various types of memory errors. However, several years ago, two researchers followed an undergraduate whose initial performance was average but climbed to 80 items after 20 months of practice (Ericsson, Chase, & Faloon, 1980). As a long-distance runner, he was familiar with the format of running times (i.e., 3- or 4-digit sequences), so he chunked the digits into this format and built those chunks into a hierarchical structure for storage in long-term memory. Rather than expanding his short-term memory capacity, he changed the task to use long-term memory, a system with a vast capacity. His increase in performance did not generalize, however: His performance on the task with letters instead of digits fell back to normal levels. Thus, although he learned some special skills (i.e., his new strategy), he did not overcome the cognitive limitations that constrain others (i.e., short-term memory capacity). Is something similar going on with trained speed readers? There is not a great deal of well-controlled research on this topic, but we turn now to some studies that have examined speed readers and have evaluated their eye movements, reading speed, and comprehension.

Llewellyn-Thomas (1962) and McLaughlin (1969) each recorded the eye movements of one speed reader and found that, as the training courses recommend, the speed readers moved their eyes down the middle of the left-hand page and then up the middle of the right-hand page, fixating particular lines only once and completely skipping most lines altogether. Using this peculiar pattern of eye fixations, the reader processes half of the material (i.e., the right-hand pages) in the sequence opposite to that in which it was written (and is normally read), and therefore in a different order than the author intended. As you might expect, when McLaughlin (1969) tested comprehension with free recall, he found that the speed reader recalled confused—and sometimes completely fabricated—information from the text. The poor comprehension calls to mind the comic Woody Allen's classic line: "I took a speed reading course where you run your finger down the middle of the page and was able to read

War and Peace in 20 minutes. It's about Russia." ('War and Peace' in 20 Minutes?, 1995).

Another study looked at two graduates of a speed-reading program who were considered by program officials to have achieved such remarkable performance that the officials contacted a cognitive scientist to test them under controlled conditions in a laboratory (Homa, 1983). When so tested, each student read an entire college-level textbook in less than 6 minutes, achieving rates of 15,000 wpm or higher. Although the students speed read the book three times, their performance on a multiple-choice test of comprehension was quite poor. Neither speed reader showed any extraordinary ability, as compared to average readers, in perceiving peripherally presented letters or identifying which words had appeared in a briefly presented paragraph. The extraordinary ability that they had achieved, the investigator concluded, was "a remarkable dexterity in page-turning" (Homa, 1983, p. 126).

Calef, Pieper, and Coffey (1999) recorded the eye movements of a group of adults both before and after they enrolled in a speed-reading class, comparing them to a group of people who did not take the class. In the pretest, both groups of readers read at about 280 wpm. After the speed-reading course, the speed readers read at about 400 wpm, making fewer fixations (and regressions) with shorter fixation durations (228 ms after compared with 241 ms before). Their comprehension score decreased from pretest (81% correct) to posttest (74%), indicating that the increased rate of speed was achieved at the expense of comprehension.

Further evidence for comprehension difficulties among speed readers came from a study by Liddle (1965; reanalyzed by Carver, 1971, 1972), who tested graduates of Wood's speed-reading program and compared them to readers who had signed up for the program but had not yet taken the course. Both groups of people were tested for both speed and comprehension on fiction and nonfiction material. The reading rates were about 300 to 1,300 wpm faster for the graduates than the control group. While test scores revealed a significant decline in comprehension among the graduates on the fiction material, the two groups showed approximately the same level of comprehension for the nonfiction material (68% for the graduates and 72% for those who had not yet taken the course). But in nonfiction material, the content is based on the real world. Thus, it is possible that the speed readers could have answered the questions correctly by knowing the answers rather than actually having read them from the text. In fact, when Carver administered the same comprehension test to a group of people who had never seen the passage, they obtained an only slightly lower score (57%) through their use of common knowledge and guessing. This qualifies the conclusion that there was no comprehension loss for the nonfiction material (in addition to the already established decrease in comprehension for fiction material).

The most complete study of the eye movements and comprehension of speed readers was carried out by Just, Masson, and Carpenter (1980; see also Just & Carpenter, 1987). They presented passages to speed readers (reading rates around 600–700 wpm), normal readers (reading rates around 250 wpm), and people who were asked to skim (producing rates around 600–700 wpm). The speed readers did better than skimmers on general comprehension questions about the gist of the passages but not quite as well as people reading at normal speed. Normal readers, who made many more fixations than the speed readers, were able to answer questions about details of the text relatively well, while skimmers and speed readers, who made many fewer fixations than normal readers, did not differ from each other on these items. They could not answer these questions if they had not fixated on the regions where the answers were located. The data thus suggest that the students of speed-reading courses are essentially being taught to skim and not really read in the sense that we use the term "reading" here. The advantage of trained speed readers over skimmers with respect to general comprehension of the text was ascribed by Just and colleagues to an improvement in what they called *extended inferencing*. Essentially, the speed readers had increased their ability to construct reasonably accurate inferences about text content on the basis of partial information and their preexisting knowledge. In fact, when the three groups of participants were given more technical texts (taken from *Scientific American*), for which background knowledge would be very sparse, the speed readers no longer showed an advantage over the skimmers, even on general questions.

So what about phenomenally fast speed readers such as Anne Jones and Howard Berg, mentioned at the beginning of this article? One advantage Jones had in reading the new Harry Potter book was having read earlier books in the series. That experience probably allowed her to capitalize on a large amount of background knowledge about such things as characters, plot structure, and writing style. Combining that background knowledge with visual sampling from pages of the new book and a highly developed ability to engage in extended inferencing (Just et al., 1980) could have allowed her to generate a coherent synopsis of the book. A more thorough assessment of comprehension achieved by speed readers like Jones and Berg, based on tests such as those used in some of the research studies we have reviewed, is lacking. Moreover, as we have seen, it is very important to assess how well a reader can perform on a comprehension test based merely on background knowledge, without having read the critical text. So, at this point, we can only speculate

about what an objective assessment of the reading comprehension of Jones and Berg would reveal.

To summarize, there is no evidence that training programs allow people to dramatically increase their reading rates while maintaining excellent comprehension. If speed readers have developed a special skill beyond the ability to turn pages quickly, that skill may be learning to skim. Effective speed readers appear to be intelligent people who already know a great deal concerning the topic they are reading about and are able to successfully skim the material at rapid rates and accept the lowered comprehension that accompanies skimming (Carver, 1985). This brings us to a discussion of skimming as a strategy to deal with the problem of having too much to read and too little time.

Skimming

Although we have shown that many elements of speed-reading training are not likely to be effective, some elements may be used adaptively to more efficiently process text. Reading faster necessarily means not reading a text in its entirety, which essentially means skimming. Taylor notes that Wood "repeatedly stated that her people are not skimming, but rather are reading" (Taylor, 1962, p. 65). Based on recordings of their eye movements, however, Taylor concluded that they closely resembled the eye movement patterns produced during skimming (Taylor, 1965; see also Walton, 1957). He tested a large group of graduates from Wood's training program and found that those who more often moved down the center of the page had the poorest comprehension of the text on a true/false test (around 50%—chance performance). So, if speed reading essentially boils down to skimming, are there more effective ways to skim?

Research on skimming has revealed important facts about what it entails and how it affects comprehension. One goal of skimming a text is to obtain a general idea about its content, extracting the important information. Therefore, the suggestion from speed-reading proponents that speed readers should zigzag down one page and up the other may be the least effective way to skim. More deliberate skimming, with more time spent on the critical portions of the text, may be more effective. In a study comparing people reading normally and skimming at about twice their normal reading rate, Masson (1982) showed that people who were skimming were less able to correctly identify statements taken from the text, regardless of whether the statements reflected important information or minor details. The equal drop in performance for important and for detailed information indicated that skimmers were not able to effectively select important information to read carefully while skipping minor details (see also Carver, 1984; Dyson & Haselgrove, 2000). Perhaps, then, the skimmers who were tested in these studies were not using effective strategies to do so. Are there more effective ways?

Effective skimmers scan a text for headings, paragraph structure, or key words to locate potentially relevant information, then read more carefully when such regions are found. Research has shown that readers who pay more attention to headings write the most accurate text summaries (Hyönä, Lorch, & Kaakinen, 2002). Indeed, a number of recent speed-reading books have provided helpful advice along these lines. For example, Konstant (2010) advocated inspection of a book's structure (e.g., its table of contents) and selective reading of the first paragraph of each section and the first sentence of every paragraph to help find important information. The central idea is that one does not need to read the same way for every reading goal. If it is necessary not to understand all aspects of a text but rather to find a particular fact, then selective reading such as skimming can help people to achieve their goal more efficiently. Duggan and Payne (2009) showed that skimming an entire text led to better memory for important ideas than normally reading only the first half or only the second half of the text, but skimming comprehension was equivalent to when subjects read only half of every paragraph at normal speed. The eye movements revealed that skimmers tended to spend more time reading earlier paragraphs and earlier pages, suggesting that they used the initial parts of the text to obtain the general topic of passages and provide context for the later parts that they skimmed in a more cursory way. Therefore, effective skimming means making sensible decisions about which parts of a text to select for more careful reading when faced with time pressure. In fact, Wilkinson, Reader, and Payne (2012) found that, when forced to skim, readers tended to select texts that were less demanding, presumably because they would be able to derive more information from such texts when skimming. This kind of information foraging is a useful method of handling large amounts of text in a timely manner.

To conclude, skimming is an important skill and may be a reasonable way to cope with the overwhelming amount of text we have to read, as long as we are willing to accept the trade-off between speed and accuracy that skimming requires. Strategies such as attending to headings and spending more time on the beginning and ending of paragraphs may improve comprehension during skimming or may allow people who are skimming to access the information they seek more effectively.

Speed-reading technologies

Although speed-reading training courses are still somewhat popular (most colleges have such a course somewhere on campus), their appeal has waned and has been

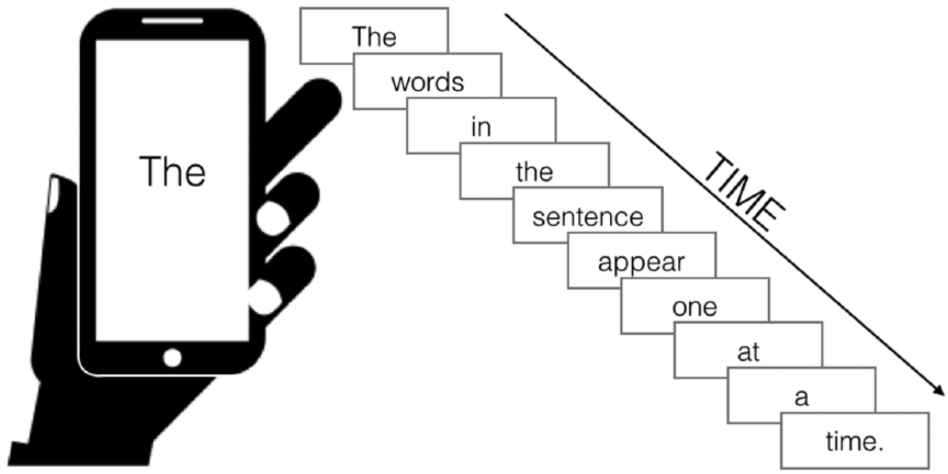

Fig. 14. A depiction of a rapid-serial-visual-presentation (RSVP) display as would be used on a mobile device. Words are presented one at a time on the screen at a device-set speed.

replaced by the appeal of speed-reading technologies. Many of these technologies are based on the claim that the eye movements we make during reading are a waste of time and that we would be much more efficient if we used a device to present words to us at a rate faster than we would normally receive them via eye movements. A further claim is that the reader need not have control over the exact sequence and timing with which the words are presented; the device can take control of these things, leaving the reader more time to process the words and their meanings.

RSVP-based technologies. Recently popular methods present words one at a time on a digital display using the RSVP technique that we discussed earlier. The appeal of such methods may reflect the fact that advocates of many of these technologies claim that no training in use of the technology is necessary. The idea is that the computer or smartphone does all the work, presenting words for the reader in rapid succession. The person can simply sit back and passively absorb the text. Because the device controls the timing, users can set their reading rate to whatever they want (e.g., 200, 500, or 1,000 wpm), regardless of what their comfortable, natural reading rate is (Fig. 14).

One recent method of this kind is used by apps based on a technology called Spritz. There are several competitor apps that are based on the same principle, some of which preceded the development of Spritz, but because Spritz has received the most attention, and because its developers have made many specific claims about the science behind it, we spend the majority of this section addressing those claims directly. For instance, Spritz included the following passage under the heading "Reading Basics" on its website, which we will walk through part by part below:

> Traditional reading involves publishing text in lines and moving your eyes sequentially from word to word. For each word, the eye seeks a certain point within the word, which we call the "Optimal Recognition Point" or ORP. . . Once the ORP is found, processing the word for meaning and context occurs and your eyes move to the next word. When your eyes encounter punctuation within and between sentences, your brain is prompted to assemble all of the words that you have read and processes them into a coherent thought. (The Science, 2015)

Consider, first, the website's mention of the optimal recognition point, which should sound familiar if you recall the optimal viewing position, or OVP (O'Regan et al., 1984), described earlier. However, contrary to the implication of the Spritz website, readers are capable of identifying words whether or not they look at the OVP; there is just a slight loss of processing efficiency if their eyes land on a different point in the word. Moreover, the research we reviewed on parafoveal preview benefit suggests that readers begin to process words before looking directly at them, rather than "once the ORP is found." To be fair to Spritz, centering words at the OVP may be an improvement over RSVP methods in which words are left justified. This is because, with left justification, words of different lengths will be placed such that their OVPs are in different locations and the reader will probably be viewing the word from a non-optimal position. However, when words are centered, as in the RSVP paragraph experiment described earlier (Potter et al., 1980), the eye will remain close to the OVP.

The idea that the brain assembles the words and processes them into a coherent meaning only when punctuation marks are encountered is also problematic. As we

have discussed, research shows that people identify words, sentence structures, and meanings incrementally. Even though some additional wrap-up processes occur at the end of a sentence (Just & Carpenter, 1980; Warren et al., 2009), people do not wait until the end of a phrase or sentence to compute its meaning (Frazier & Rayner, 1987; von der Malsburg & Vasishth, 2013).

Spritz has also been quoted by media outlets as saying that only 20% of the reader's time is spent processing content while 80% of the time is spent moving the eyes (e.g., Luchette, 2014). First, let us address the implication that the time spent processing content and moving the eyes must be mutually exclusive. For this to be true, all cognitive processing must halt during an eye movement, which is not the case (Irwin, 1998). Instead, the brain continues processing the information it had obtained on the prior fixation. Moreover, saccades during reading last approximately 20 to 35 ms (we will use 25 ms for simplicity), and fixations last approximately 250 ms. Thus, our estimate of the percentage of time spent moving the eyes (between one fixation and the next) is only about 10% of the total reading time. If we assume that we are always processing content while reading (e.g., recalling prior parts of the text, identifying the current word, making sense of the sentence as a whole), then a more accurate statement might be that 100% of the time is spent processing content and, during that time, the eyes are moving 10% of the time.

In a blog post on their website, Spritz also claimed that "every saccade has a penalty in both time and comprehension" and that "right-to-left saccades are discombobulating for many people" (Why Spritz Works, 2014). However, as we discussed earlier, eye movements are under control of the brain and are used to access the text in precisely the way we need it to be presented. Thus, they certainly do not waste time. Eye movements are a useful aspect of the reading process because they are sensitive to, and can compensate for, difficulties understanding the text. They do so by dwelling longer on difficult or unexpected words and by permitting regressions (Schotter, Tran, & Rayner, 2014). Readers are often unaware of the regressions they make, unless they deliberately pay attention to what their eyes are doing. A regression is more likely to be the solution to discombobulation (i.e., rereading to fix a failure in comprehension) than a cause of it.

One possible solution to the inability to reread in RSVP would be to incorporate a "go back" button on the device that would repeat the text for the reader, a feature that many apps using RSVP technology, including Spritz, have added. However, many of these buttons merely start the text (or sentence) over from the beginning. One recently announced version of RSVP technology to be released for the Amazon Kindle claims that it will allow readers to use their finger to scan through the text continuously in order to move backward or forward to a particular word. This is an improvement over only being able to start at the beginning of a sentence in that it allows for more flexibility in moving through the text. However, it has not been shown that these methods for regressing (or skipping forward) in RSVP are as effective as the eyes are in conventional reading, in which readers have a spatial representation of the text and a sense of where to move their eyes to clarify something and where to return to continue reading. In order to do this in a truly effective way, the device would need to know how far back in the text to go and would need to repeat the text from that point. Regression behavior in reading is one of the less understood aspects of the process, so even generating a general principle for this would be difficult—not to mention that there is substantial variability both across and within individuals in the sequence with which they reread words (von der Malsburg & Vasishth, 2011).

Another concern about apps using RSVP is that they do not allow for parafoveal preview. As we have discussed, a large body of research using the moving-window paradigm (see Rayner, 2014) and boundary paradigm (see Schotter et al., 2012) has shown that information from more than just the currently fixated word is used. Some information obtained from the next word before it is directly fixated is used to give the reader a head start on processing it; if this preview is denied (e.g., if the word is masked until it is fixated or not presented at all), reading time for the word is longer than if it had been visible. With the single-word RSVP method, readers do not have, and therefore cannot take advantage of, preview information.

An important concern about RSVP-based apps regards the limits that such a technique may pose for comprehension. In the "Rapid Serial Visual Presentation" section above, we described a number of studies that showed similar levels of comprehension for full text reading and RSVP when words were presented at a normal rate. It appears that, at least when comprehension is measured as it was in those studies, the elimination of parafoveal preview and of opportunities for regressive movements to earlier parts of a text do not markedly undermine text understanding when RSVP is used. But two crucial caveats must be emphasized. First, when pauses between sentences were not included in RSVP presentations of text, comprehension clearly suffered (Masson, 1983). Second, speeding text presentation beyond normal reading rates consistently led to reduced levels of comprehension and memory (Juola et al., 1982; Potter et al., 1980). These results indicate that the mental operations responsible for assembling viewed words into meaningful ideas and retaining them in memory cannot be completed if adequate time is not provided. Therefore, the

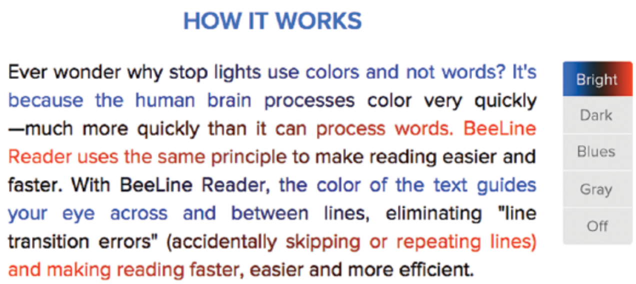

Fig. 15. A depiction of the BeeLine Reader display as presented on the BeeLine Reader website (www.beelinereader.com). Words in the sentences are colored depending on their position in a line. Text transitions along each line in a gradient (red, blue, black, and/or shades of gray) such that the end of one line and the beginning of the next are presented in the same color. Reprinted from the BeeLine Reader website (http://www.beelinereader.com/). Copyright 2015 by BeeLine Reader. Reprinted with permission.

promise that RSVP can produce faster reading without compromising understanding and memory is not supported by the research we reviewed.

As of the writing of this article, we are familiar with only two published studies that directly compared traditional reading to reading with (an approximation of) Spritz (Benedetto et al., 2015; Dingler, Shirazi, Kunze, & Schmidt, 2015). Only one of these studies objectively compared comprehension in RSVP reading and conventional reading (Benedetto et al., 2015). That study involved a passage of text taken from George Orwell's *1984*, and participants were allowed to pause the RSVP stream whenever they wanted. Taking these pauses into account, the average reading speed in the traditional reading condition and that in the RSVP condition were very similar and somewhat slower than normal reading (200 and 209 wpm, respectively). Reading via RSVP increased eye fatigue relative to traditional reading and, although accuracy was equivalent on comprehension questions that required making inferences, it was poorer on comprehension questions that assessed literal comprehension of the text. These data suggest that readers were still able to get the gist of the passage when reading at normal rates via RSVP but that their ability to maintain a veridical representation of the wording of the text was impaired. It is likely that even the gist representation would have been impaired at faster RSVP rates. Additional work needs to be done to evaluate reading using technologies such as Spritz, and this work will need to be presented in peer-reviewed conferences and journals so that it can be evaluated by the scientific community.

Based on the research that has been done on normal reading and RSVP, we suspect that presentation of moderately complex texts via RSVP apps will not allow people to achieve the goal of greatly increasing reading speed (e.g., by doubling or tripling their normal rate) while maintaining good comprehension. The real practical application of RSVP may be for wearable technology like smartwatches and glasses with optical displays that have only enough space to present one or two words at a time. The RSVP method may be the only viable way to display text on these screens. If the message is not too long or complex, RSVP may suffice to get it across.

Color-based technology. Another technology that has been suggested as a way of making reading faster and easier but that has not received as much attention as RSVP-based procedures relies on manipulating the coloring of a text. The BeeLine Reader (Fig. 15) colors lines of text in a gradient from one end to the other, such that the end of one line and the beginning of the next are colored similarly. The idea behind this approach is that a significant problem in reading is the ability to make accurate return sweeps and that reducing these errors will improve reading. As we have discussed, however, return sweeps are not the complicated part of reading (Just & Carpenter, 1980)—language processing is. Thus, any savings in reading time provided by making return sweeps more efficient may constitute only a minimal improvement in the efficacy of reading as a whole.

Practice reading

As we have suggested, effective skimming can be one way to increase reading speed while maintaining at least a moderate level of comprehension and to ascertain a certain keyword or fact or the gist of a topic. What other research-tested methods are there for increasing speed without sacrificing comprehension? As we will see in this section, modest improvements are possible, but there are cognitive and visual limitations that cannot be ignored.

Practice with reading, and in particular reading to comprehend, does help. But it helps slowly and does not cause drastic increases in speed. The importance of practice is widely appreciated for skills such as playing sports or musical instruments. We would not throw someone into a pool and expect them to swim without having learned and practiced the skill of swimming. We would not expect someone to lift weights over and over and become a better football player, because practice means engaging in a complex task in its entirety. Practice is also important for cognitive skills, and reading is no exception. The kind of practice that will help reading is practice that helps people to identify words and comprehend better, not just take in visual information faster. Indeed, as we saw earlier, reading speed is related more to one's language-processing skills than to the ability to control one's eyes. If visual information comes in faster than the comprehension system can process it, the increased speed is wasted on broken comprehension.

The practice that is required to become a better reader is thus practice with language—a conclusion that is not surprising, given that language is what writing represents. Moreover, written language uses some vocabulary and syntactic structures that are not commonly found in speech, and practice with reading can give people practice with these.

One specific example of how practice with language can help reading is related to the effects of word frequency that we discussed earlier. As we saw, fixation durations are shorter for common words such as *house* than for uncommon words such as *abode* (e.g., Rayner & Duffy, 1986; see Rayner, 1998, 2009). However, as the reader sees *abode* more and more, its frequency in the reader's experience increases. Thus, the more often you read an uncommon word, the more common it becomes, and you will be able to read that word more easily and quickly in the future (Acheson, Wells, & MacDonald, 2008). In addition to making individual words more frequent, reading can introduce you to new words, increasing their frequency above zero for you. Reading more, and reading varied texts, will increase your vocabulary and will benefit reading more than reading the same passage again and again.

Another example of how practice with language can help reading comes from the findings reviewed earlier showing that context has a strong influence on fixation durations (Ehrlich & Rayner, 1981; Zola, 1984; see Rayner, 1998, 2009). That is, readers spend less time on words that are more predictable because of the prior sentence context than words that are not predictable in context. Therefore, more experience with language will lead you to generate more and better expectations about upcoming words and to be better at extended inferencing. This is why it is important to read a diverse set of texts: Expanding your knowledge through reading about different topics will allow you to generate better expectations about what the text is about to say. That may be the basis for some anecdotes about the speed-reading abilities of famous people, such as that President Kennedy could pick up a copy of the *Washington Post* or the *New York Times* and read it from front to back in a few minutes. However, consider the knowledge and information that someone like Kennedy would bring to the task of reading the newspaper. As president, he was briefed about important world events each day and was involved in generating much of the policy and events reported in the newspaper; thus, he probably had first-hand knowledge of much of what was described. In contrast, the average person would come to such a situation with very few facts at his or her disposal and would probably have to read an article rather carefully in order to completely understand it. To read rapidly, you need to know enough about a topic to fit the new information immediately into what you already know and to make inferences.

Conclusions

Many people wish to read faster by finding a special form of reading in which they read more quickly with excellent comprehension, ideally without much effort or training. In this article, we have seen that there is no such magic bullet. There is a trade-off between speed and accuracy in reading, as there is in all forms of behavior. Increasing the speed with which you encounter words, therefore, has consequences for how well you understand and remember the text. In some scenarios, it is tolerable and even advisable to accept a decrease in comprehension in exchange for an increase in speed. This may occur, for example, if you already know a lot about the material and you are skimming through it to seek a specific piece of information. In many other situations, however, it will be necessary to slow down to a normal pace in order to achieve good comprehension. Moreover, you may need to reread parts of the text to ensure a proper understanding of what was written. Bear in mind, however, that a normal pace for most readers is 200 to 400 wpm. This is faster than we normally gain information through listening, and pretty good for most purposes.

Authors' Note

The first draft of this article was submitted a few days before Keith Rayner passed away after a long and hard-fought battle with cancer. The numerous studies of his described within this article represent only a fraction of the important, influential, and high-quality work he conducted over four decades in the fields of reading research and cognitive psychology. Rayner's contribution to science is profound (for a more complete tribute, see Clifton et al., 2016), and he proposed the current article because he felt that it was important to share the knowledge we have gained from experimental science with the general public.

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