claims about evidence to be found in the references cited in scientific journal articles are frequently inaccurate.[3] By allowing readers to more easily access this evidence, hypertext could support a more thorough peer-review discipline of the scientific literature.

3. Landauer regrets that I did not discuss empirical psychological research on electronic journal design. I had discussed some of this research in a recent article that identified the role of cognitive psychologists in the design of electronic journals,[4] so I focused this article on other concerns. In any event, Landauer is better qualified than I to write the review he seeks, and I urge him to do it.

4. Here is the context in which I remarked that the first-copy costs of electronic journals are likely to be "significant."[5] Academic publishers fear that if electronic articles can be instantly and perfectly copied by readers, it will be difficult to establish self-supporting electronic journals. To reproduce n copies of a journal and break even, a publisher must sell those copies at

$$\text{price} = (\text{first-copy costs})/n + (\text{cost of reproducing 1 copy}).$$

Because scholarly journals have limited markets, n is small. So if first-copy costs (which include costs for editing, indexing, and formatting) are large, then the break-even price will be high. How high can publishers set prices? Not very high if academics are buying, because they can reproduce their own photocopies cheaply. As Landauer notes, electronic first-copy costs may be substantially lower than print first-copy costs. Fine. But if the cost to academics of making "electronic photocopies" is almost nil, then even small first-copy costs will be significant if these costs make the break-even price higher than academics will pay. The Pacific Bell example may not apply here because the customers for its technical literature are unlikely to copy those documents.

The conclusion, however, is not that electronic journals cannot be published, but that like print journals, electronic journals may require public subsidy. This raises important equity considerations, among many other public interests in the development of the information infrastructure. These public concerns have a claim on the attention of scientists that is equal to the claim of the important cognitive research conducted by Landauer and his colleagues.

Notes

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3. J. Evans, H. Nadjari, and S. Burchell, Quotation and reference accuracy in surgical journals: A continuing peer review problem, *Journal of the American Medical Association, 263*, 1353–1354 (1990).

4. W. Gardner, The electronic archive: Scientific publishing for the 90's, *Psychological Science, 1*, 333–341 (1990).

5. Gardner, note 1, p. 76. Please note that the claim that costs will be "very high" is Landauer's reading, but is not in my text.

Word-Initial Letter Sequences and Reading

Susan D. Lima

The past 25 years have witnessed a remarkable blossoming of cognitive psychologists' interest in reading. Much of the attention has been focused on the fundamental processes of word recognition: In reading a sentence, component words must be identified before higher order comprehension processes can proceed. Most researchers envision some type of lexical access mechanism by which a word is matched with the appropriate representation in the mental lexicon. In this review, I claim that the initial letter sequences of words play a key role in word recognition during reading. Of relevance to this issue are results from experiments in which an eyetracker is used to monitor adult subjects' eye behavior during reading.

EYE BEHAVIOR IN READING

The regions of the retina useful in reading are the central foveal region (encompassing approximately 2° of visual angle), where visual acuity is highest, and the surrounding parafovea, or near-periphery. Although readers may have the subjective impression that their eyes sweep smoothly across a line of text without pausing, nothing could be further from the truth. In fact, our eyes are almost always still while we are reading. Reading proceeds via a series of relatively long pauses called fixations, separated by very fast, jerky movements called saccades. In reading English, one normally proceeds along one line of text at a time, foveally fixating points in a left-to-right direction. During a fixation, the eyes typically pause for approximately 200 to 250 ms, and each fixation is followed by a saccade to another location in the text. Most saccades are forward; they average approximately eight to nine character spaces in extent, and 20 to 30 ms in duration. In skilled adult readers, approximately 10% to 15%

of saccades are regressions, or right-to-left movements. Because the average duration of a fixation is 10 times that of a saccade, the eye is still more than 90% of the time during reading. During saccades, there is a kind of functional blindness, so that the visual information useful in reading is gathered virtually exclusively during the fixations.

SOME DETERMINANTS OF FIXATION DURATION

Adult readers typically fixate most of the words on a line of text.[1] Recent reading research using eye behavior measurement builds on two fundamental observations about these fixations. The first is that the duration of a fixation on a word is sensitive to the processes being performed on that particular word at that particular point in the text. One way of restating this observation is that the fixation duration on word *n* varies as a function of the perceptual and cognitive difficulty of processing word *n*. Strong links have been found between the duration of a fixation and key characteristics of the fixated word, such as word frequency, contextual relevance, and lexical ambiguity. Low-frequency words, for example, receive longer fixations than high-frequency words.[2]

The second observation about fixation durations is that there is a processing benefit attributable to parafoveal preview of a word before the word is actually fixated; that is, processing time during fixation on word *n* decreases if word *n* was in the parafoveal region prior to fixation. Parafoveal information is essential for optimal reading performance. In fact, depriving the reader of all parafoveal information to the right of the fixated word can cause as much as a 40% decline in reading rate. Surprisingly, however, the spatial extent within which useful parafoveal information can be extracted is quite limited.

Experiments on the role of parafoveal preview in reading have used an eyetracker interfaced with a computer that is continually informed of the exact location of the subject's point of fixation. This arrangement permits execution of the *moving-window* technique, pioneered by McConkie and Rayner,[3] in which text is displayed on a computer monitor, and the computer makes very quick textual display changes that are contingent on the exact point of the subject's fixation. A region of text (the *window*) around and including the fixated word is normal, but text outside this region is abnormal. The window moves in synchrony with the subject's eye movements, so that normal text appears wherever the subject fixates; it is impossible for the subject to fixate the abnormal text. This ingenious technique allows manipulation of the size of the window, the symmetry or asymmetry of the window, and the type of text mutilation outside the window. The underlying hypothesis is that the mutilation of text will impair reading only if the mutilated text falls within the reader's *perceptual span*, or the region of information that can be processed during a fixation.

WORD-INITIAL SEQUENCES IN THE PARAFOVEA

Data from moving-window experiments have shown that in reading English, the perceptual span to the left of fixation does not extend any farther than the beginning of the word currently fixated. That is, reading efficiency is virtually undisturbed by mutilated text displayed to the left of the fixated word. The perceptual span does, however, extend farther to the right than to the left, as might be expected given the scanning direction in reading English.[4]

In one experiment,[5] subjects read text while the fixated word was normal and either full or partial information was present to the right of the fixated word, the rest of the letters on the line of text being replaced with letters of the same general shape as the letters that should have been there. It was found that preserving the beginning two letters, or word-initial bigram, of the parafoveal word to the right of the fixated word resulted in faster reading than a control condition denying preview of the word-initial bigram. Furthermore, preserving the parafoveal word's initial trigram (i.e., first three letters) resulted in still faster reading. However, as long as the letters beyond the word-initial trigram were physically similar to the letters that were supposed to be in those positions, there was little additional benefit from preserving letters beyond the third letter of the parafoveal word. Thus, it was shown that readers benefit primarily from correct parafoveal preview of the initial two or three letters of the word they are about to fixate. (In reading Hebrew, parafoveal preview benefit accrues not to the right of fixation but to the left, showing that the asymmetry of the perceptual span depends on scanning direction and is not "hard-wired."[6])

So far, I have explained that fixation duration on word *n* is sensitive to at least two factors: (a) characteristics of word *n*, such as word frequency, and (b) whether or not word *n* had its initial letter sequence available for preview during the prior fixation. It appears, therefore, that each word is usually processed dur-

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ing at least two different fixations: Word *n* is processed not only during fixation on itself (fixation *n*), but also during the fixation prior to the fixation on itself (fixation $n - 1$). Information from the two fixations is somehow combined to result in accurate, efficient reading of word *n*.

One plausible explanation of the integration of information across the two fixations can be termed an information-accrual account. In this account, parafoveal processing entails priming of the lexical representations of a set of candidate words that includes the correct word and other words similar to it, all of which begin with the same sequence of letters. Visual information from the parafovea (fixation $n - 1$) contributes activation to lexical representations, with word-initial information weighted more heavily than information from other parts of the parafoveal word. When word *n* is directly fixated, its representation has already been partially activated, and its recognition has thus been facilitated. This facilitation leads to a shorter fixation than could have occurred had there been no preview of the word's initial letter sequence while it was in the parafoveal region.

INFORMATIVENESS OF WORD-INITIAL LETTER SEQUENCES

In English and similar languages, word-initial fragments tend to be more informative than fragments in other positions. Try to guess the words in the sentences from the fragments presented below:

Plea____ dre___ wi__ fol___.

____eful ___ple __ll ___ive.

__egan_ _lat__ _il_ _rac_.

Most people find that the identity of the words can be more easily guessed from knowledge of the first letters than from knowledge of other letters.[7]

An interesting and relevant finding that has emerged from eye-tracker experiments is that the eye tends to land preferentially at a certain location within words. The *preferred viewing location* is about halfway between the first and middle letters of a word, such as the third letter of a seven-letter word.[8] When subjects are forced to fixate at less convenient locations in a word, word recognition is delayed.[9] The fact that the preferred viewing location tends toward the word-initial region suggests that readers have a tendency to fixate words in a potentially highly informative area.

The relative contributions of initial and ending word fragments to word recognition were tested directly in an experiment in which two-syllable words (e.g., *basket*) and nonwords (e.g., *blater*) were presented foveally, and the subject's task was to decide as quickly as possible whether each item was a word or a nonword.[10] Letters were not presented all at once, but in a time-staggered fashion; one of the syllables appeared on the screen 90 ms before the other, with the entire word or nonword remaining on the screen until the subject's response. It was found that preview of initial syllables (e.g., BAS . . .) led to lexical decision times 25 ms faster than preview of ending syllables (e.g., . . . KET). In fact, preview of ending syllables contributed no benefit at all relative to a control condition in which letter preview was entirely unavailable, implying that lexical access cannot begin until word-initial letters are processed.

Given the evidence from this experiment and the evidence from eye-tracking experiments that preview of correct word-initial bigrams or trigrams is essential for efficient reading, one plausible hypothesis is that the informativeness of a word's initial bigram or trigram will influence both the foveal and the parafoveal processing of that word. According to this *constraint hypothesis,* lexical access will be fastest when the size of the set of word candidates is highly constrained by the word-initial sequence. For example, *dwarf* will be easier to recognize than *clown* because *dwa* is consistent with so few other words, whereas *clo* is consistent with several words.

Inhoff and I[11] tested two predictions of the constraint hypothesis: (a) A high-constraint word (e.g., *dwarf*) should receive less fixation time than a low-constraint word (e.g., *clown*), and (b) a high-constraint word should benefit more from parafoveal preview than a low-constraint word. To test these predictions, we used the moving-window technique to present sentences such as *The weary dwarf hated his job* (or *The weary clown hated his job*) with or without parafoveal preview of word-initial sequences. The findings were intriguing: Neither prediction of the constraint hypothesis was supported. In fact, low-constraint words, such as *clown*, received reliably shorter, not longer, fixations than high-constraint words, such as *dwarf,* and the two types of words benefited equally from having their word-initial trigrams available in the parafovea prior to fixation. Thus, although both the high- and the low-constraint words benefited from having been available for word-initial parafoveal preview, supporting the claim that word-initial information is important in word recognition, an increase in the degree of constraint imposed by the word-initial trigram did not help lexical access, but actually seemed to impair it. Because the pairs of critical words were closely matched on key characteristics, including word frequency, syntactic category, length, and contextual predictability, these variables can be ruled out as possible explanations of the reverse constraint effect that was observed. Recently, similar results have been reported for French stimulus words in gender classification, naming, and semantic classification tasks.[12]

The advantage of *clown* compared with *dwarf* is not completely unexpected, however, because as constraint of a word-initial sequence increases, familiarity of the sequence decreases. It may be relatively difficult for readers to process sequences of letters as unfamiliar as *dwa*. This interpretation is consistent with currently influential connectionist models in which the existence of "orthographic neighbors" (similarly spelled words) may enhance, rather than impair, recognition of a given word.[13] According to such models, the lexical representation of a word that has neighbors will receive more activation from representations at the letter level than a word that has no neighbors, so that, somewhat paradoxically, a word that looks like other words tends to be recognized more quickly than a word that looks unique. Andrews reported just such facilitatory effects of increasing neighborhood size, particularly when stimulus words were low in frequency.[14]

IMPLICATIONS

The data reviewed here point to the conclusion that there is a special usefulness of visual information extracted from word-initial letter sequences in parafoveal preview and in the process of contacting representations in the mental lexicon. In a prominent model of lexical access, Taft and Forster[15] proposed that lexical access proceeds via a left-to-right parsing of the stimulus word. According to this model, the initial letter sequence of a word has special status because this sequence forms an access code that allows lexical contact via a sequential search of representations in an "access file"; these representations are linked to full lexical representations in the lexicon proper. In contrast, connectionist or parallel activation models have not tended to assign differential weights to different portions of words, so that usually, letters in word-initial positions are seen as making contributions equal to those of letters in other positions. However, parallel activation at the letter and word levels of mental representation does not preclude differential weights for different letter positions, and the evidence presented here may indicate that greater weight should be assigned to information accruing from letters in word-initial positions than to information accruing from letters in other positions.

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Notes

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Recommended Reading

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