

Eye-Fixation Patterns During Reading Confirm Theories of Language Comprehension*

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Eye-movement patterns during reading are consistent with proposition-by-proposition models of speech comprehension. (1) Fixation times are least affected by word length at ends of clauses: this confirms the theory based on the study of speech comprehension that, at such points, attention is directed inward to text integration. (2) Fixation time for words at the end of clauses is longer for canonical sequences which conform to the pattern, "N-V-N=actor-action-object"; this confirms the view that complete semantic integration of such sequences is routinely delayed until their completion. A two-variable model based on principles of exhaustive visual search and speech comprehension accounts for 80% of the fixation durations in a sample paragraph from Just and Carpenter (1980) and Thibadeau, Just and Carpenter (1982). This comprehension-based model compares favorably with their models constructed within a production-system framework. This result clarifies the relationship between reading and listening.

I. INTRODUCTION AND SUMMARY

In the present paper we demonstrate that eye-movement patterns in reading are consistent with a model originally developed to explain the comprehension of spoken language. We propose a comprehension-based model of visual scanning that assumes only that gaze duration on each word is determined by length-in-letters and serial position in a clause. Length-in-letters

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alone accounts for 75% of the variance in word fixation times in a sample paragraph; another 3% of the variance is accounted for if the model treats short, frequent function words as 1 letter long; an additional 2% is accounted for by information about whether each clause-final word ends a canonical clause structure or not. The comprehension-based model compares favorably with three recent production-system descriptions of eye-fixation patterns, each of which depends on at least 11 variables. The explanatory force of the production-system models is vitiated by the fact that the variables are chosen arbitrarily without constraint from an independently supported model of language comprehension.

The comprehension-based model is quantitatively adequate, involves only two independent variables and facilitates an understanding of the relation between reading and listening. In particular, the unity of the processes underlying the two modes of comprehension suggests that there is a single mechanism for language processing.

II. A COMPREHENSION-BASED MODEL OF SPEECH PERCEPTION

A general picture of speech comprehension has been developing during the past decades. The output of comprehension processes is a nonlinear semantic representation of meaning: semantic representations are not literal abstractions of actual speech sequences, but are recoded into a different form. This principle is widely agreed on by researchers who agreed on little else, (e.g., Bever, 1970a; Lindsay & Norman, 1977; Marslen-Wilson, & Tyler, 1975; Schank, 1972). The perceptual analysis of such representations gives special status to the quick recognition of structural frames, specified both by word-class order and by particular configurations of function morphemes (Cooper & Cooper, 1980; Kuno & Oettinger, 1963; Marcus, 1977; Townsend and Bever, 1982; Woods, 1970).

In English the most salient structural frame for a complete proposition is a "nounphrase-verb-nounphrase" sequence, corresponding to "agent-action-object." Bever (1970, a & b) and Slobin and Bever (1982) propose that such sequences are "canonical" in English. Children demonstrate an early development of this schema by their systematic misunderstanding of sentences in which the first nounphrase is not the agent of the verb of which the second nounphrase is the object (e.g., passives, object-first cleft sentences; Bever, 1970b; deVilliers & deVilliers, 1973; Maratsos 1974). In adults, canonical sequences are comprehended directly by means of a set perceptual schema. Experimental support for this is based on the many experiments showing that sequences with noncanonical word order are relatively hard to understand, even when semantic constraints indicate what the subject and verb must be. (For reviews, see Bever, 1970a; Clark & Clark, 1977; Fodor, Bever & Garrett, 1974; Townsend & Bever, 1984).

Finally, a sequence of words is perceptually grouped as a function of its semantic completeness. That is, the linear sequence is organized into "perceptually relevant propositions," segments corresponding to natural units of meaning, notably semantically interrelated phrases and clauses. One behavioral reflection of this claim is that semantically related, adjacent phrases are grouped together during perception. Such a view is commonly held as well, though researchers differ on the functional importance of specific surface properties of such groupings and on the mechanisms that yield their segregation, (e.g., Bever, Lackner, & Kirk, 1969; Carroll, Tannenhaus, & Bever, 1979; Frazier & Fodor, 1978; Fodor, Bever, & Garrett, 1974; Kimball, 1973; Schank & Abelson, 1977).

This sketch suggests some structural properties of perceptually relevant propositions but does not specify the processes that cause segmentation. On the average, the beginning of such a unit stimulates less semantic recoding than does the end (Bever, Garrett, & Hurtig, 1973). Accordingly, listeners alternate between attending to the stimulus during a proposition and organizing it semantically near its conclusion. That is, the theory of speech perception we have outlined explains the following experimentally demonstrated facts: during a perceptual proposition, attention is relatively focussed on the acoustic signal; towards the end of the perceptual proposition the mental activity of assigning a final organization to the meaning increases and draws attention away from external stimuli (Abrams, 1973; Abrams & Bever, 1969; Bever & Hurtig, 1975; Seitz, 1972; Valian, 1971).

Reading may use the same comprehension principles as those outlined for listening. First, it is a near universal claim that readers construct an "abstract" semantic representation of the visual signal (see the review in Gibson & Levin, 1976, pp. 438-482). Second, frequent function morphemes are read as unanalyzed units (Drewnowski & Healy, 1977; LaBerge & Samuels, 1974). For example, (Healy, 1980) readers fail to detect misspellings and target letters in such words. Third, a few studies demonstrate that major phrases are units of reading. For example, eye-voice span (EVS) studies demonstrate that skilled readers tend to chunk sentences into phrases (Levin & Kaplan, 1968; Schlesinger, 1969). Children as young as fourth graders start to group oral reading into phrase units and skilled readers more often end the EVS at phrase boundaries than do poor readers (Levin & Turner, 1975).

Finally, there is some direct evidence for the claim that reading comprehension activity increases at the end of major semantic units. Readers pause in subject-paced reading tasks at the end of clauses and the length of these pauses is a function of the difficulty of the text (Aaronson & Scarborough, 1976; Haberlandt, 1983; Mitchell & Green, 1978). It is the case that readers can detect fewer silent *e*'s at the end of a clause than the beginning; this suggests that at that point readers are less attentive to the physical characteristics of the linguistic stimulus (Muncer & Bever, 1983, 1984).

III. WHAT EYE-FIXATIONS TELL US ABOUT READING

Eye-fixations during normal reading are an external sign of the amount of attention devoted to each point in a sentence. As the eye scans printed material, its center of focus jumps from point to point. The reader is functionally blind during eye-movements between resting points (Matin, 1974; Volkman, 1976). Accordingly, the resting patterns of the eye offer an external motor record of what a reader is looking at and for how long. (See Tinker, 1958 and Rayner, 1978, for reviews of studies of eye-movements while reading.)

In particular, we can now examine the implication of the theory of speech perception for gaze-duration patterns. Just and Carpenter (1980) presented a study of eye-movement patterns of 14 subjects, each reading 15 popular science essays with an average length of 132 words. They provided us with data from the one paragraph of 140 words that they published as a measure against which to test the validity of their computer simulation, *READER* (Thibadeau, Just, & Carpenter, 1982). We used these data to test the model of attentional variation during reading originally developed to explain comprehension processes during speech.

The first step in applying the model of speech comprehension to such data is to isolate aspects of eye-fixations that are based on unique features of the printed page. The minimal unit of print is the letter. In the limiting case, a diligent reader must bring every letter into foveal vision at least once. An eye-movement pattern that results in each letter being viewed at least once requires the eye to move between 3 and 6 letters each time, given the type size and visual distance used by Just and Carpenter, (1980).¹ We are not suggesting that readers move their eyes a fixed number of character spaces between each fixation. Eye-movement data exhibit a great deal of individual subject variation, both in fixation duration and extent (Rayner, 1978). Readers, however, tend to make relatively short saccades while reading scientific text (Buswell, 1938), so it is reasonable to assume that Just and Carpenter's subjects moved their eyes on an average within the range of 3-6 character spaces. Just and Carpenter report an average reading speed of 225 words per minute, suggesting that their subjects' reading rates were well within the range necessary to view each character at least once.²

On Just and Carpenter's method of data collection and analysis, the relative length of gaze-durations correlates with the number of fixations per word. Shorter words may not be fixated at all by some or all of the readers,

¹Just and Carpenter, 1980, state that within their experimental design, one degree of visual angle is equal to three characters.

²For the one paragraph of 140 words that we analyzed, the mean fixation time per character is 41 ms., which translates into 244 words per minute. The eye fixation pattern of a college student illustrated in Just and Carpenter (1980, p. 330) fits well within this range; the only indication of a saccadic extent of more than 6 characters occurs over the words "of the," both of which we suggest below are read as single units.

resulting in shorter mean gaze-durations for words of 4 letters or less.³ This property of visual perception justifies the prediction that length-in-letters correlates with mean word-fixation time as presented by Just and Carpenter, (1980). We found that length-in-letters alone accounts for 75% of the variance in word-by-word data in the sample paragraph provided us by Just and Carpenter.⁴ This value is much higher than the variance accounted for on the basis of syllable-length, which is 45%.

Certain lexical features correlate with the way in which length-in-letters fails to predict exact fixation time. Fixation times to content words do not vary consistently from the predicted times. Nor do fixation times to function words with variable reference, such as pronouns, depart consistently from the predicted times. However, fixation times to frequent, closed-class function words tend to be over-predicted by length-in-letters; that is, 31 cases are over-predicted while only 5 are under-predicted. As we noted, several scholars have proposed that such words are read as units, regardless of their objective length. If we define the virtual length of "of," "and," "the," "to" and "in" to be one letter, the minimal length of a lexical unit, the amount of the variance accounted for by virtual length-in-"letters" in the sample paragraph is 78%.⁵

Of course, a single-variable account of the variance in eye-fixation durations is of greatest interest if it interacts with an independently motivated theory of comprehension. The behavioral feature of speech comprehension reviewed before describes fluctuations in attention to the linguistic

³Kliegl, Olson, & Davidson, 1982, make a similar point, they state that "since there is little change in fixation duration between one, and two-fixation cases (Kliegl et al., in press; O'Regan, 1981; Rayner, 1979), the average gaze duration to a large extent reflects the probability that a given word will be fixated" (p. 289). Kliegl, et al. go on to suggest that Just and Carpenter's analysis is flawed both by their reliance on hierarchical regression analysis and by their method of data collection, especially their use of mean gaze duration as opposed to individual fixation patterns. Notice that in spite of the fact that we use mean gaze durations supplied to us by Just and Carpenter, our model is not subject to the same criticism. We predict, on the basis of syntactic features, where mean gaze duration diverges from the expected value computed on the basis of that word's length-in-letters. The method of averging gaze durations does not alter the significance of our model's predictive power. (For an alternative method to Just and Carpenter's, see Kliegl et al., 1982).

⁴Just and Carpenter added the duration of any fixation on the space between words to the gaze-duration of the following word (p. 335). Accordingly, we increased the length of each word by one, e.g., "a" = 2, one letter and one space; "energy" = 7, six letters and one space. Just and Carpenter also added the durations of fixations on commas and periods (plus the durations of fixations to the space immediately following the period) to the gaze duration of the preceding word (personal communication, 1981). We increased the length of words followed by punctuation accordingly, e.g., "spins," = 7, six letters and one space; "it." = 5, three letters and two spaces.

⁵Function words are highly frequent, closed class, generally short, with little or no semantic content. Our selection of these 6 words (we include "a," but since "a" is already one letter, its virtual length does not differ from its actual length) is quite conservative; not only are they closed class, short words, with little or no semantic content, they are also the 6 most frequent words in the English language according to Kucera and Francis, 1967.

signal: during a perceptual proposition, attention to the signal is high, while towards the end of the proposition, attention is reduced because of final processing of the meaning. This systematic fluctuation in attention predicts that word-length will correlate with gaze-duration to different degrees at different points in a propositional unit. In particular, duration will be most strongly controlled by word-length during a perceptual proposition, and will be controlled by other factors at the end of the proposition, when attention is less focussed on the actual word. For the same reason, the per-letter reading time will be lower at the end of a perceptual proposition. Finally, the 0-letter intercept value of the empirically derived regression will be higher at the end of a perceptual proposition, reflecting the fact that meaning integration time is added at the end of such units regardless of the length of the final word. All these predictions are confirmed by the data from the sample paragraph. To define the perceptual proposition, we follow Just and Carpenter's analysis of the paragraph into "sectors," which comprise what they call "meaningful units." These sequences correspond well to complete propositions. Table 1 presents the best-fit correlations, slopes and intercepts of word length against eye-fixation durations for different serial positions within sectors. The probability of these five samples being drawn from the same population can be rejected at the .005 level ($\chi^2 = 15.66/F = 4$). Using a Fisher *r*-to-*Z* transformation, each of the *r* values for the 1st, 2nd and middle positions (.92, .93, and .92, respectively) are significantly higher ($p < .01$) than the *r* value for the last position (.58). Each of the *r* values for the 1st, 2nd and middle positions are significantly higher ($p < .05$) than the *r* value for the next-to-last position (.73). The combined *r* values for the first three positions are significantly higher than the combined *r* values for the last two positions ($p < .001$). None of the *r* values among the first three positions differ from each other, nor do the *r* values for the last two positions.⁶

TABLE I
Position in Clause

| | <i>1st</i> | <i>2nd</i> | <i>Middle</i> | <i>Next-to-last</i> | <i>Last</i> |
|------------------------|------------|------------|---------------|---------------------|-------------|
| Number | 18 | 17 | 70 | 17 | 18 |
| <i>r</i> ² | .85 | .87 | .85 | .53 | .34 |
| Slope (msec/letter) | 61 | 41 | 38 | 35 | 30 |
| O-intercept | -107 | -9 | 0 | 33 | 65 |
| Content Words | 7 | 10 | 36 | 8 | 16 |
| Function Words | 11 | 7 | 34 | 9 | 2 |
| Mean Word Length | 5 | 6.1 | 6.5 | 4.5 | 7.8 |

⁶For the purpose of analysis, clauses of 5 words or more were divided into 5 positions; first word, second word, middle word or words, next-to-last word and last word; clauses of 4 words were divided into first word, second word, next-to-last word and last word; the one clause of 3 words was divided into first word, middle word, and last word.

As predicted, word-length accounts for the most fixation duration at the initial positions of the sector, where it accounts for over 85% of the variance; it accounts for far less at the end of the sector—53% for the next-to-last words and 34% for the last words. Furthermore, the per-letter increment in reading time is lower for end-of-sector words. Finally, the 0-intercept for end-of-sector words is higher than for other positions. Examination of such potential covarying features in each serial position, as average length-in-letters or proportion of content words and function words, shows no systematic relation that might independently account for the serial pattern. The high ratio of content words to function words in the final position does not account for the low correlation. In the middle position, for content words alone, length-in-letters accounts for 70% of the variance in gaze-duration while in the final position, for content words, length-in-letters accounts for 30% of the variance. The relative effects of serial position are similar for sectors that do and do not end sentences.

Such systematic variation in the predictive power of word length is a strong confirmation of the model of attentional variation developed for listening to speech. The eye-fixation pattern provides a running record of the fact that the sensitivity of the attentional system shifts from the physical signal to other variables at the ends of meaningful perceptual units.

This leaves open the question of exactly what controls fixation time at the ends of the perceptual units. According to the speech comprehension theory, it is by this point that comprehenders must have carried out integration of the internal structure and meaning of the semantic unit. The role of the so-called “canonical sequence” schema in speech perception offers a possible explanation of the variation in fixation durations at clause-final positions. On the comprehension theory, a canonical sentence schema is treated as a coherent, uninterruptable unit; accordingly, a canonical sequence is processed for meaning most fully near its conclusion, while a non-canonical sequence is more fully processed by substrategies while it is being heard. This difference predicts that fixation duration on final words of canonical sectors are *longer* than predicted by length-in-letters alone; and fixation durations on final words of noncanonical sectors are *shorter* than predicted by length-in-letters alone. We tested this as far as we were able, by separately correlating length-in-letters for sector-final words that end canonical as opposed to noncanonical clauses. Although our analysis is hampered by a small sample size, (there are 5 canonical sectors in the test paragraph⁷ and 12 noncanonical sectors, see Appendix A), our results suggest a fruitful direction for further research.

Readers spend more time per letter on final words in canonical sectors ($p < .001$; $t = 5.81/F = 15$). This reflects the relatively high processing load

⁷With Just and Carpenter's procedures, gaze-duration on the final word of the paragraph may be contaminated by the need to make a motor response in order to terminate the section. We decided on the basis of this to disregard the final sector of the paragraph.

at the end of canonical clauses. In contrast with this, the per-letter reading time for nonfinal words in canonical sectors is not significantly shorter than in noncanonical sectors ($p > .1$; $t = 1.12/F = 81$).⁸ Length-in-letters accounts for significantly more of the variance in gaze durations for nonfinal words in canonical sectors than for nonfinal words in noncanonical sectors ($r = .95$ compared to $.85$; $p < .01$, using a Fisher r -to- Z transformation/ $F = 113$). This supports our hypothesis that readers distribute their fixations relatively evenly across canonical clauses until they reach the final word.

If we add a canonical/noncanonical variable to our analysis of sector-final words in isolation the amount of variance accounted for in that position alone rises from 34% to 79%. If the comprehension-based model includes a canonical/noncanonical variable for sector-final positions in an overall analysis, it accounts for 80% of the overall word-fixation time. It is striking that this final version of the comprehension-based model uses 1 continuous variable motivated by visual search (length-in-letters), and 1 discrete variable motivated by a perceptual theory (final word in a canonical clause, or not).⁹

IV. THE COMPREHENSION-BASED MODEL COMPARED TO PRODUCTION-SYSTEM MODELS

Just and Carpenter constructed three partially distinct production-system models of reading, all of which account for approximately the same variance in eye-movement data. Their original model (Just & Carpenter, 1980) describes the effects on eye-fixations durations of 17 visual and linguistic variables. Subsequent revisions of their model include a computer simulation of the reading process (READER) and a further attempt to define the variables that account for eye-movement patterns. Their models account

⁸This paradoxically suggests that readers take longer to process canonical clauses than they do noncanonical. If this is indeed true, then our model needs further refinement and revision. However, notice that even in the one paragraph we examine the trend is in the predicted direction; the per-letter reading time for noncanonical, nonfinal words is longer than for canonical nonfinal words, reflecting that readers resort to alternate processing strategies during the processing of noncanonical sectors. If the sample size was increased this trend might reach significance. It is also a well known fact that readers make the greatest number of regressions in unpredictable, syntactically complex clauses, i.e., noncanonical clauses (Rayner & Frazier, 1982; Wanat, 1978). As Just and Carpenter, 1980, did not record time spent in regressions, it may be that, in fact, readers take longer to process noncanonical clauses, but because so much of this time results from regression, the recorded data do not bear on this.

⁹Note that the decision to treat a small number of short function words as a minimal unit of length is a part of the theory, not a free mathematical variable.

for respectively 76%, 67% and 81.7% of the variation in the data from the sample paragraph we have been discussing.¹⁰

Our model is quantitatively as adequate as Just and Carpenter's; it requires far fewer variables; in addition, it is based on an independently motivated, empirically derived, theoretical basis for our selection of pertinent variables. Just and Carpenter's approach, on the other hand, is to use as their theoretical basis a production-system framework within which to construct their models. Unfortunately, a production system is too powerful to explain anything: "[Production-system] systems are too flexible because some [Production-system] system could be proposed to account for almost any behavior, human or machine, and because there is no way of specifying beforehand the correct [Production-system]" (Anderson, 1976, p. 106). Thus, the production-system framework provides Just and Carpenter neither with a procedure nor theoretical justification for selecting specific variables. The absence of a procedure determining how each variable is assigned means that no specific model is confirmed by the data. The absence of a constraining general theory means that the data can not confirm any general theory, even if a specific model were spelled out.

As Table 2 shows, each of Just and Carpenter's models involves a partially distinct set of variables with no marked improvement in predictive power. We are not claiming that all the decisions about the variables are either correct or incorrect. Rather they are arbitrary just because Just and Carpenter's procedure of model building is not constrained by theory. The fact that Just and Carpenter have presented three distinct, but similarly successful models for the same data reflects the flexibility of their general theoretical approach. In the limiting case, such flexibility is its own undo-

¹⁰Just privately reported to us that their 17-variable accounts for "approximately 76%" of the variance in the critical paragraph. He, likewise, reported that their revised model accounts for 81.7% of the variance for the sample paragraph, but added that the regression analysis of the "flywheel" passage included only 10 of the 11 variables tested in Thibadeau et al.; so, one could view this subset of their model as having only 10 variables. It is of some interest to test the adequacy of our model of eye-movement patterns theory when additional, nonlinguistic variables are included. Two salient ones noted by Just and Carpenter are words that begin lines and unpredictable words. (Nine Columbia graduate students judged the predictability of each word on the basis of previous content, length in letters and punctuation. "Highly unpredictable words" were those that received predictability ratings one and one-half standard deviations below the mean.) A multiple regression analysis that includes these two additional variables along with the original two accounts for 83.4% of the variance in the sample paragraph. Accordingly, this 4-variable model compares favorably with Just and Carpenter's 17-variable model that accounts for 76% of the variance in the critical paragraph, and with the 11-variable model of Thibadeau et al., that accounts for 81.7% of the variance. Of course, our 4-variance model is tailored to the best fit for the sample paragraph alone. We should expect that our model would do less well on a particular paragraph if its parameters were based on the full data set.

ing. If an approach allows for a large number of distinct models equally adequate to the same data, it is subject to *reductio ad multas* if not *absurdum*.

TABLE II
List of Variables

| 1980 MODEL | 1982 Model | READER |
|------------------------|------------------------|------------------------|
| no. of syllables | no. of letters | no. of letters |
| log frequency | log frequency | log frequency |
| beginning of line | beginning of line | |
| novel word | novel word | novel word |
| | digit | |
| agent | skipped word | skipped word |
| instrument | head noun modification | head noun modification |
| direct/indirect object | | |
| adverb/manner | | |
| place or time | | |
| possessive (genitive) | | |
| verb | | |
| state/adjective | | |
| rhetorical word | | |
| determiner | | |
| connective | | |
| last word in sentence | last word in sentence | last word in sentence |
| last word in paragraph | last word in paragraph | last word in paragraph |
| | first mention of topic | first mention of topic |
| | first content word | first content word |
| | in paragraph | in paragraph |

Thibadeau, Just and Carpenter (1982) present a computational model of the same data that appears at first to provide independent verification of their revised model. They devised a specific computer model of reading, "READER," which utilizes an independently constructed programmed framework for production models, "CAPS" ("Collaborative Activation-based Production System"). They claim that READER is "a natural language understanding system that reads the text word by word, and whose processing time on each word corresponds to the human gaze-duration on that word" (p. 158). We cannot give a detailed critique of CAPS and READER, since many aspects are not presented in Thibadeau et al., (1982). We can, however, outline some limitations and difficulties in this model.

1. It is a model of recognition of stored linguistic knowledge, not comprehension or acquisition of new knowledge.
2. Although counted in CAPS, the number of available independent parameters in READER is quite large. This includes functions of

- length-in-letters and word frequency, a distinct activation for each production level, and productions of various levels of description.
3. The psychological duration of one CAPS cycle turns out to be quite short.¹¹ This means that the theoretical and empirical force of a quantal step represented by each CAPS cycle is muted, especially as each is computed as only one of the many discrete steps which combine to form the serial and parallel processing framework proposed by Thibadeau et al.
 4. In asserting that "There is *functional parallelism* among processes, so that operations of different types or of the same type can be executed concurrently, in temporally parallel streams of activity" (p. 161), Thibadeau et al. (1982) reduct the impact of their claim that READER models the time course of human gaze-durations. The length of time spent on any one word is determined by the time duration of the longest process, i.e., the one taking the greatest number of CAPS cycles to complete. On any given word, there is no way to verify from the data the existence of processes other than the longest, since their occurrence is obscured by those processes that involve more cycles.
 5. The theoretical descriptive power of CAPS would seem to be that of an associative model, without the typical behaviorist requirement that every theoretical term be directly observable—limited exactly to those associations (i.e., "productions") that are already listed. (For similar criticism, see Allport, 1980 and Fodor, 1983.)

The use of CAPS as a general program and READER as a specific implementation of it does not constrain possible models to a small enough set to make significant the partial confirmation of READER. CAPS allows for many models of different kinds that leave to imagination the elaboration of any particular "READER." What is needed is a narrow theory of reading that can constrain possible READERS to a small, and therefore, potentially relevant set.

IV. CONCLUSION

We have found that the pattern of eye-fixation durations supports the model of language comprehension originally based on the study of speech

¹¹Thibadeau et al. imply that the psychological duration of one CAPS cycle is quantitatively equivalent to 32 ms, the increase in gaze-duration per letter in a word. "There is one additional CAPS cycle for each additional letter in a word" (p. 32). However, they also report that the word "contains" requires a minimum of 25 cycles to process (Table V). Since the mean gaze-duration on "contains" is 305 ms (M. A. Just, personal communication), this suggests that one CAPS cycle is less than 12 ms.

comprehension. On our model, a diligent reader of a technical text uses an average saccadic jump that guarantees that all letters are within focus at least once. As in listening, the points at the end of semantic units are devoted primarily to semantic integration, which reduces the importance of word length for fixation durations. The observed eye-fixation patterns confirm these claims.

It would be pointless and is impossible to account for every variable that can govern eye-fixation patterns during all kinds of free reading. The explanation of some of the variance that remains for the comprehension-based model may depend on a precise theory of what causes perceptual clause complexity. Our results suggest that if we ever have such a complexity metric, we will be able to test it with eye-fixation data.

In brief, eye-fixation data can confirm specific proposals about reading, once they are embedded in a theory that takes into account processes of both visual recognition and the comprehension of spoken language. The efficacy of the comprehension-based model for both reading and listening demonstrates its role as a general language processor. This offers a theoretical basis for the view that individual variation within the normal range of reading abilities is based on variation in the accuracy of a single language comprehension system. (For a general discussion, see Perfetti & Goldman, 1976; Townsend, Carrithers, & Bever, 1984.) At a more theoretical level, the unity of the basic comprehension processes used in reading and listening supports the notion that there is a general-purpose mechanism for all language processing.¹²

APPENDIX A

Deviations of the observed value of the final word from the value predicted by letter-length establish the following rank-ordering for Just and Carpenter's (1980) sectors of the flywheel passage. Note that the rank-ordering is from the most under-predicted word, "spokes," to the most over-predicted word, "automobile."

1. Another type, the "superflywheel," consists of a series of rimless spokes.
2. If it spins too fast for its mass,
3. that powers the drive shaft.
4. One type of flywheel consists of round sandwiches of fiberglass and rubber.
5. Every internal-combustion engine contains a small flywheel

¹²Fodor, 1983, discusses the importance of such a single language processing "faculty" within a general theory of the mind. Our results are consistent with his proposal, but with many other variants as well.

6. that converts the jerky motion of the pistons into the smooth flow of energy
7. providing the maximum possible storage of energy
8. Flywheels are one of the oldest mechanical devices
9. The more energy can be stored in it.
10. known to man.
11. when the wheel is confined in a small space
12. This flywheel stores the maximum energy
13. The greater the mass of a flywheel and the faster it spins,
14. Any flywheel will fly apart.
15. But its maximum spinning speed is limited by the strength of the material
16. it is made from.
17. as in an automobile.

We assigned canonical or noncanonical status to each sector on the basis of the the following criteria:

1. A sector is noncanonical if it does not have a verb or requires a complement—sectors 9, 13, and 18.
2. A sector is noncanonical if the nounphrase in the sequence, nounphrase-verbphrase-*X*, does not correspond to an agent. (The variable *X* can be an object as in *NP-VP-NP*; an adjective as in *NP-VP-Adj*; or null as in *NP-VP*.)—sectors 7, 8, 10, 11, 12, 14, 16, 17, 18.
3. A sector is noncanonical if the main verb is not finite (inflected in the present tense)—sectors 8, 10, 11, 15.

Note that words like “unlimited” are not passivized verbs but rather adjectives. There are no corresponding active sentences such as “the flywheel unlimited the energy.” Note also that sector 7 does not conform to canonical order in that is verbphrase, “converts into” is divided into two parts by the object.

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