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ABSTRACT

This report argues that the Mean Gaze Durations or eye movement records used by M. A. Just and P. A. Carpenter to develop a model of reading comprehension are an inappropriate measure of processing time. An alternative approach called Read to Right of Gaze (RRG-1), which assumes that more than one word can be read during a fixation, is recommended instead. Research results are reported that also support the assumption that the perceptual span is asymmetrical to the right, allowing skipped words to be read on preceding fixations; therefore, the processing time for the majority of words in a passage is quite different from the time recorded using Mean Gaze Durations. (AEA)

CENTER FOR THE STUDY OF READING

Technical Report No. 207

THE ROCKY ROAD FROM EYE FIXATIONS TO COMPREHENSION

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Abstract

In their article "A Theory of Reading: From Eye Fixations to Comprehension" Just and Carpenter (1980) present a model of reading comprehension. As support for this model, they present a simultaneous multiple regression analysis of Gaze Durations, a measure derived from eye movement records which is presented as a measure of processing time. The present paper discusses the issues involved in deriving a measure of processing time from eye movement records and suggests that Gaze Durations are an inappropriate measure. Additionally, the type of analysis they employ can only provide weak support for a real time theory of reading.

The Rocky Road from Eye Fixations to Comprehension

Over the last several decades, one primary concern of psychologists has been measuring the real-time durations of mental events. The presumed durations of different types of mental processes has served as a data base for many theories of mental processes. One of the primary reasons for its popularity is that the temporal aspect of mental events often seems to be directly measurable even if other more qualitative aspects are not. However, defining a theoretically interesting mental event whose duration is unambiguously measurable often proves to be a problem.

It has been apparent at least since the studies of Buswell (1937) that eye movement records might provide real time measurement of the mental processes involved in reading and other cognitive tasks. This is a particularly enticing possibility since eye movements are a naturally occurring observable behavior that are a normal part of reading, and it is reasonable to propose that they are indicants of the temporal aspect of mental processes that accompany reading. In their paper entitled "A Theory of Reading: From Eye Fixations to Comprehension," Just and Carpenter (1980) present a model of reading comprehension that claims to account for the duration of eye fixations of college students reading scientific passages. The paper proposes a general view of cognitive processes involved in reading and provides an approach to using eye movement data both to test this view and to provide chronometric information about the hypothesized processes. While we agree that eye movement data can serve as a source of information about the temporal characteristics of mental processes occurring during reading, the appropriate use of this information involves a number of complexities that are not addressed in the Just and Carpenter article. The present paper will describe some of these complexities and will suggest that some aspects of the seemingly straightforward analysis employed by Just and Carpenter are inappropriate for reading situations.

The use of eye movement data to test theories of the duration of mental events involved in reading can be broken down into three steps; assigning processing time to various regions of the text, assessing the validity of the assignment procedures, and evaluating the ability of various theories to account for variations in processing time.

Associating Fixation Times with Areas of the Text

Unfortunately, eye movement records themselves do not directly indicate the amount of mental processing time spent on each unit of text. Rather, they only indicate that the eye fixated certain locations[1] in the text in a particular sequence for certain periods of time. If one desires a measure of how much processing time is allocated to each successive segment of the text, this record, or processing time profile, must be constructed from the eye movement records. The construction of these processing time profiles is based on assumptions about the nature of perceptual and language processes during reading. These assumptions are of critical importance. If the wrong assumptions are selected, the resulting profiles will not accurately represent the amount of time attributable to each segment of text. Hence, any further analysis will be based on faulty data.

Issues Involved In Assigning Processing Time

A typical example of eye movement records is shown in Figure 1. Consider fixation 2 which fell on the letter i in the word white

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Insert Figure 1 about here.
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and lasted 190 msec. The question that must be answered is "what area of the text was being processed during that 190 msec?" If the answer to this question were known, the 190 msec could be assigned to that area in some manner, and the same thing could be done with each and every fixation. This process would then yield a processing time profile for each subject on each passage. Some procedure could then be used to average over subjects and produce a single profile which would be interpreted as representing the processing time characteristics or demands of the text for this type of reader. Exploring various regression analyses to predict this profile would then provide an indication of the types of factors influencing processing time. Clearly, however, the entire approach rests on the ability to construct the processing time profile that accurately represents how much time was allocated to each unit of the text.

In deciding what area of a text is being processed during a particular fixation, three important issues must be addressed.

The processing unit. First, it is necessary to decide on the unit most appropriate for characterizing the area processed during a fixation. If people spend their time reading words, then the duration of each fixation should be assigned to some word or words, as Just and Carpenter have done.

if syl.ables are an appropriate unit, then fixation duration may be assigned to some syllable or syllables, disregarding word boundary information. Similarly, letters could be an appropriate unit (McConkie, Hogaboam, Wolverton, Zola, & Lucas, 1979). There are, of course, still other possibilities, including units that are defined by degrees of visual angle, ignoring syllable, letter, and word boundaries. The profiles generated from a given set of eye movement records will differ depending upon the unit chosen.

The region processed during a fixation. Once a unit has been chosen, there must be some rule for deciding which particular units of the text were processed during each fixation. This is an issue which is currently under experimental investigation (Underwood, 1980; Hogaboam, Note 1; McConkie, Note 2). It includes two sub-issues. The first concerns the use of fixation location information to identify the area of text being perceived during the fixation. While it is certainly true that fixation location indicates the general area of current attention the exact nature of this relationship has not yet been determined. Studies by McConkie and Rayner (1976) and Rayner (1975) indicate that this attended area typically includes the foveal-central letter and lies asymmetrically to the right. It is not large, perhaps extending no more than 16 letters to the right, and perhpas considerably less (Underwood, 1980). Still, critical information is missing. One particularly bothersome problem is the possibility that the location of the region attended during a fixation is not fixed, but varies with respect to the fixation location. Just and Carpenter assume that always and only the directly fixated word is processed during a fixation. McConkie et al. (1979) proposed that the region processed may be approximately bounded by two successive fixation locations when a forward saccade intervenes. Other possibilities obviously exist, as well.

The second sub-issue concerns the possibility of an eye-mind lag. If there is a lag between the time a unit is perceived and the time the information from that unit enters into various aspects of the comprehension process, it is quite possible that units being perceived on a particular fixation are not exactly the same units as those that are determining the duration of that fixation. Just and Carpenter propose the eye-mind assumption, suggesting that information obtained from a unit (a word) is processed as far as the preceding text allows during the fixation on which it is perceived. There are other models which suggest a lag, or dissociation, of perception and of processing a word (Bouma & DeVoogd, 1974). While there is substantial evidence that information obtained during a fixation can influence the duration of that fixation (see reviews by Rayner, 1978; Levy-Schoen & O'Regan, 1979) it still remains quite possible that some aspects of the processing licensed by an additional word are not completed until after the fixation is terminated. This has been a difficult question to treat experimentally because it requires prior solution to the problem of the region of text being acquired during a fixation.

Dividing time among multiple units. The third issue arises when it is proposed that two or more units are processed during a particular fixation. In this case, how should the duration of the fixation be allocated to these units? Should the full fixation duration be assigned to all units or should it be divided among them in some manner? Just and Carpenter avoid this problem by assuming that no more than one unit is processed during a fixation, an assumption which will be challenged later.

Presently there is not overwhelming evidence available to strongly motivate particular positions on many of the issues discussed above. It is clear, therefore, that constructing processing time profiles from eye movement records necessarily involves making a number of choices among competing assumptions about the nature of the perceptual and cognitive processes involved in reading. Thus, the claim that some pattern in a particular profile supports a particular theory of reading must be evaluated in light of the choice of assumptions employed in constructing the profile.

Gaze Duration Assumptions

Just and Carpenter create processing time profiles by constructing the Gaze Duration on each word of a text. We shall use the term Gaze Duration to refer to a single subject's processing time profile constructed by the procedures given in Just and Carpenter and outlined below. "Mean Gaze Durations" will refer to the averaged profile constructed from the Gaze Duration profiles. The procedure for constructing Gaze Durations is straightforward. For each subject, if a fixation falls on a word, all of the fixation time is assigned to that word. If a word is fixated more than once, all fixation durations are summed and assigned to the word. Data from rereadings, some blinks, saccades, and fixations following regressions are deleted. The Gaze Durations from different subjects reading the same passage are then averaged on a word by word basis to form the Mean Gaze Duration for each word. Mean Gaze Durations serve as the dependent variable in the regression analysis used to support their model of reading.

To support the argument that Mean Gaze Duration can be directly interpreted as measuring comprehension time, Just and Carpenter present two claims about the nature of eye movements during reading and two assumptions about their interpretation. The first claim is that "readers generally can't determine the meaning of a word that is in peripheral vision." Studies by McConkie and Rayner (1975) and Rayner (1978) are cited as supporting this claim. Presumably this claim is intended to mean that readers are only processing the currently fixated word during a fixation, since this is the claim that is needed to interprete Gaze Duration as a measure of comprehension time. It would follow, therefore, that one and only one word is processed on each fixation, and that word is the one being fixated. The second claim is that readers tend to fixate almost every word in a text except short function words. As support for this claim, they cite observations of their own data and reports from other studies where there tends to be about one fixation for every 1.2 words. The two assumptions presented, the eye-mind and immediacy assumptions, state that processing of a word starts as soon as possible, presumably shortly after being fixated, and that the eye remains fixated on a word until it is processed as far as the preceeding text allows. Taken together, these claims and assumptions allow Just and Carpenter to "try to account for the total duration of comprehension in terms of the gaze duration on each word."

Problems With Mean Gaze Duration

We will argue that the first claim is unsupported by the evidence cited and that, in fact, evidence suggests that, typically, readers acquire information from words falling to the right of the fixation point. Secondly, the claim that essentially every word is fixated is a simple misconception of the nature of eye movement records. Data will be presented indicating that a substantial number of content words are commonly skipped during reading.

Where do we read? In order to interpret Mean Gaze Duration as a measure of comprehension time, it is necessary to establish the claims that the time consuming processing occurring during a fixation is due to the processes licensed by the currently fixated word and the preceding text. The studies of McConkie and Rayner (1975) and Rayner (1975), however, clearly indicate that during a fixation information is acquired from words to the right of the fixated word. In fact, Rayner's (1975) conclusion was that readers can semantically interprete words that begin 1-6 letter positions to the right of fixation. At this time, of course, they are fixating a previous word. It must be remembered that the fovea-periphery distinction is retinally defined, with the fovea typically taken to be about 2° of visual angle. With normally encountered print sizes, then, the fixated letter plus two to five additional letters with fall on the fovea. However, in normal reading conditions words lying in the near-periphery can also be identified (Bouma & DeVoogd 1974). Therefore, it is not uncommon that the word to the right of the fixated word lies partially, and sometimes wholly, on the fovea itself, and it is often the case that the right adjacent word falls on a retinal area that permits identification.

How often are words skipped? An empirical investigation. In order to examine the second claim, that almost every word is fixated during reading, we have analyzed the eye movement records collected as college students read a passage about the history of Alaska. Eye movements were monitored using a limbic reflective technique described in McConkie, Zola, Wolverton, and Burns (1978). This equipment samples eye position once every millisecond and is accurate to within one character position when the subject's head is stable.

The text consisted of a 417 word passage about the history of Alaska and was displayed on a CRT. Subjects were instructed to read the passage for comprehension and told there would be questions after they finished. The passage was presented one line at a time and the subjects had a button which controlled the presentation, bringing the next line onto the screen within .1 second. The CRT was located 19 inches from the eyes, with three letter positions occupying one degree of visual angle. In order to determine fixation location, a calibration pattern was presented before and after the text.

Of 44 college students who served as subjects, the data from 20 were not used because of head movement. This was a high proportion because the subjects were not yet well trained in remaining still, although all subjects had read at least two warm-up passages. For the remaining 24 subjects, the data were accurate to within 2.5 character positions or less. Each fixation was examined to determine if it was centered on the letter of some word, and if so, how long the word was (number of letters). Fixations preceeding and following blinks were excluded, as were fixations centered between words, or which lay to the right or left of the line of print. This excluded about 10% of all fixations. The results of this analysis are shown in Table 1.

Insert Table 1 about here.

The data were inspected to determine the reasonableness of the claim that almost all words are fixated. The number of words per fixation was 1.12, slightly less than the average reported in the literature cited by Just and Carpenter. It is tempting to interpret this to mean that almost every word is fixated but this is clearly not the case. Of the 10,008 different words (417 words x 24 subjects), only 5994 received 1 or more fixations, or 59.9%. Thus, about 40% of the words received no fixations. The apparent discrepancy results from many words receiving multiple fixations. The fourth line of Table 1 presents the ratio of number of fixations on words of a given length to the number of different words of that length that were fixated. This ratio thus indicates the average number of fixations per word for words that received at least one fixation. Not surprisingly, longer words have a greater tendency to receive multiple fixations. This result has also recently been reported by Rayner (1979).

It is also apparent from the fifth line of Table 1 that short words have a higher probability of being skipped than longer words. It is sometimes concluded from the relationship that, for the most part, it is the short function words that are being skipped. Indeed O'Regan (1979) has reported a tendency to skip the word "the." There are several points to be made regarding this claim. First, while short words have a higher probability of being skipped than long words, even long words have a substantial probability of not being fixated. Four-, five-, and six-letter words received no fixations with probabilities of .373, .276 and .235 respectively. And these figures are even lower than those reported by Rayner and McConkie (1976), who found four-, five-, and six-letter words are not fixated with probabilities of .52, .41, and .27. Clearly, it can not by concluded that, in general, every medium length or longer word is fixated. Secondly, it is not the case that all short words are function words. Table 2 presents a list of all 3-letter words occurring in the text. The probability of fixating each at least once was calculated and appears in

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Insert Table 2 about here.

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the second column. It is clear that the words the and and which occur very frequently, tend to be skipped more than other three letter words, $Z = 5.47$, $p < .001$. This agrees with the conclusion reported by O'Regan (1979). It is also true that these words account for a large porportion of skipped three-letter words (55%). However, there were 4014 words (40%) that were not fixated. When the words in the passage were categorized as either function words or nonfunction words, about 70% of the function words and 25% of the nonfunctions were skipped.

There is one additional aspect of Table 1 worth noting. The third row presents the obtained number of fixations on words of each length. The last row presents the corresponding number of fixations that would be expected if the number of fixations were strictly proportional to the area of the text taken up by words of that length. That is, this row represents the expected number of fixations if each fixation were randomly placed somewhere in the text. There are two points to note here. First, a Chi square test indicated that the obtained pattern differed from that expected under a random model, $\chi^2 = 86.5$, $p < .01$. This result is similar tc that reported by Rayner and McConkie (1976) and has been taken as evidence against the random model of eye guidance. Just and Carpenter cite this and other evidence that word length may be used to guide the eyes. A second aspect of this data, however, is also important. The correlation of expected and obtained number of fixations is $r = .989$. This is strong evidence that fixation location is largely random with respect to word length. This is not, of course, evidence that eye guidance is random, or that word-length patterns are not involved. It is possible to conceive of models that use word-length information for guidance, but yet yield data patterns that are also predicted by a random model when the data are aggragated on this manner. The point we wish to make here, however, is that the probability of fixating words of various lengths does not unambiguously indicate that word length strongly influences eye guidance in a simple manner. It seems likely that factors weakly correlated with word length are mediating the observed effects of word length.

The Just and Carpenter paper provides no data indicating the proportion of words not fixated. From the analysis above, it seems likely that this proportion is considerably larger than that paper implies, and is not confined to function words. This will have important implications both for interpreting the Gaze Duration profile, and for the regression analysis which uses that profile as data.

One further analysis was conducted to investigate the question of skipping words during reading. Since 40% of the words were not fixated, it may be tempting to assume that on four out of every ten forward saccades, on the average, the eyes were sent beyond the next word on the line. However, again the summary statistic does not provide a good indication of the moment-to-moment behavior of the eyes. Table 3 presents data concerning the probability of skipping words of various lengths when they lie immediately to the right of the fixated word.

Insert Table 3 about here.

It is important to remember that this analysis is in terms of proportion of forward saccades, while the more usual analysis presented in Table 1 is in terms of proportion of words. While the proportion of one-, two-, and three-letter words that received no fixation was high (.847, .741, .616 respectively), the proportion of times that these were skipped, given that they lay immediately to the right of a fixated word and the saccade was forwardgoing, is smaller (.627, .560, .548 respectively). On the other hand, while the proportion of unfixated four- and five-letter words is .373 and .276, the probability of skipping words of this length given that they lie to the right of a fixated word is larger (.460 and .346). Thus, the difference in the likelihood that words of different lengths lying immediately to the right of a fixated word will be skipped is not as great as the summary data of Table 1 would suggest. It is interesting to contrast data for two-letter words (.56) where most are function words with that for four-letter words (.46) where most are content words. The difference is only 10 percentage points. Thus, the function- vs. content-word distinction may not be as important in determining whether words are skipped as is often suggested.

These results have important implications for constructing processing time profiles. Since about 40% of the words are not being fixated, and many of these are nonfunction words, it does not seem plausible to assume that only the fixated words are involved in time consuming processes. Rather, it seems likely that more than one word is processed on a significant number of fixations. In constructing Gaze Durations, however, time is only assigned to words that receive fixations, and a zero is assigned to words that do not receive fixations. If words that are not fixated are in fact read during some fixation, the construction of Mean Gaze Duration errs in two ways. First, the time assigned to each nonfixated word is underestimated by being assigned a zero. Second, the time assigned to fixated words is overestimated on all fixations where, in fact, more than one word was read. Gaze Durations, then, provide an accurate estimate only when one and only one word is read during a fixation.

When Mean Gaze Duration is calculated by averaging over subjects, the resulting mean is some unspecified combination of overestimates, zeros, and some correct estimates. The effect of this problem would be lessened if these errors were random. However, it is likely that the probability of fixating particular words is related to their function in the comprehension process. Thus, Gaze Durations will introduce systematic bias in measured processing time in accordance with the factors governing probability of fixation. For instance, the data presented in Table 3 indicates that shorter words are fixated less frequently. In constructing Gaze Durations, then, more zeros are assigned to shorter words and hence, more zeros will enter into the mean as word length decreases, leading to smaller Mean Gaze Duration. Hence, it is likely that if one finds smaller means for function words, which tend to be shorter, this may be due solely to varying probabilities of fixation. The same may be true of any linguistically defined category which differs from another category in probability of fixation. It should be noted that calculating Mean Gaze Durations weighted by the number of fixations does not avoid this problem, but only reduces the bias in proportion to the number of times two or more words are processed on one fixation. It would still be true that time spent processing one word would be attributed to another.

<u>Summary</u>

We have argued that Mean Gaze Durations cannot be directly interpreted as a measure of processing time as there is good reason to believe the underlying assumptions are wrong. There were essentially two lines of evidence advanced. First, there is experimental evidence suggesting that the word to the right of the fixated word is often read during the fixation (McConkie & Rayner, 1976; Rayner, 1975). Secondly, the general pattern of fixation locations is not in harmony with the assumptions underlying the construction of Mean Gaze Durations. An alternative approach to constructing a processing time profile will be presented below.

Relating Processing Time to Variables

Although there are problems with Mean Gaze Durations as measures of processing time, it is still true that the measure varies in systematic ways that are predictable by theoretically motived constructs. This is evident in the results of regression analyses reported by Just and Carpenter. Additionally, using a similar set of independent variables to predict Mean Gaze Durations, we have also found systematic variations in the data presented above, although the results do not agree in detail.

The fact that variables that are expected to affect processing time (word frequency, word length, etc.) do indeed show such effects on Mean Gaze Duration has dual consequences. It increases confidence in the effect of those variables on processing time and increases confidence that Mean Gaze Duration is indeed a measure of processing time as claimed. This process of bootstrapping a measure of cognitive processing is common in Psychology, and arguments for and against it are beyond the scope of this paper. It should be pointed out, however, that a measure will appear to boot in this manner whenever it measures any correlate of the processes being influenced by the independent variables. We have argued that Mean Gaze Duration does not provide an accurate measure of processing time, but it does boot in the above sense. This is presumably because Mean Gaze Durations correlate, at least weakly, with processing time.

Even if Mean Gaze Duration is not an accurate indication of processing time, it could still be regarded as an observable aspect of the eyes' behavior during reading. This behavior could be predicted to some extent by a particular theory of reading, and hence provide some support for the theory. The arguments presented here do not address this approach as long as the Mean Gaze Durations are not construed as measures of processing time. If this approach were taken, then the model presented by Just and Carpenter would be a model of eye movement behavior and not a model accounting for processing time. Additional assumptions would then be needed to relate this behavior to processing time. This may be one promising approach.

An Alternative Approach to Constructing Processing Time Profiles

Determing exactly how a processing time profile should be constructed from the eye movement records is a difficult task. Methods of constructing these profiles will have to continually be revised to reflect the results of further research on perceptual and real-time language processes during reading. We have argued above that Gaze Duration can be rejected on the basis of currently available evidence. However, it could be regarded as a reasonable first approximation and would remain the method of choice unless an alternative method were available which is more consistent with present knowledge about perceptual processes during reading. Therefore, we propose the following alternative approach, not as a final solution, but as a way of avoiding the known problems of Gaze Duration. We will call this the RRG-1 method (Read to Right of Gaze).

The RRG-1 method makes the following assumptions. First, if a word is fixated it is read during that fixation. Second, if a word is skipped, it was read during the fixation preceding the forward saccade that skipped the word. The word fixated immediately preceding a regressive saccade is read during that fixation, but not the words skipped by the regression.

If only one word is read during a fixation, the fixation duration is assigned to that word. If two or more words are read during a fixation, the fixation time is equally distributed among them. If a word is counted as being read on more than one fixation, the times are summed. Additionally, on the rightmost fixation on any line, it is assumed that all the words from the one fixated to the end of the line were read.

While there are similarities between this measure and gaze duration, the resulting profiles are quite different. Some of the assumptions are shared, such as presuming that the word is the appropriate unit of analysis and that processing is immediate. The RRG-1 method, however, incorporates the assumption that more than one word can be read during a fixation, and that in the majority of instances the eye movement records can be used to indicate on which fixation words are read. In particular, it is assumed that the perceptual span is asymmetrical to the right and that skipped words are read on preceding fixations. This difference in assumptions results in a different assignment of processing time for the majority of words in a passage, as it affects not only the times associated with the skipped words but the fixated words as well.

To determine if the RRG-1 measure of processing time bootstraps itself as discussed above, profiles were constructed for the 24 subjects who participated in the above experiment. The profiles were then combined by finding the average time for each word, averaging over only those subjects who provided data on a given word. Regression analysis showed significant main effects (F tests, $p < .05$) of syntactic category, printed frequency, spatial frequency, number of syllables, number of letters, position in sentence, and line position. Hence, the measure boots in the sense discussed above, as it is sensitive to variables which should influence processing time. A simultaneous multiple regression analysis of these data using a set of independent variables similar to the set used by Just and Carpenter indicated that their model accounts for a statistically significant proportion of the variance. Thus, there is no reason to doubt, at this point, that the factors identified in their model contribute to processing time.[2]

It is important to note, however, that a simultaneous regression analysis can only provide weak support for a real-time model of reading. In particular, it can only indicate how a certain set of variables predict processing time, but it cannot be used to support assertions about the manner or order in which these factors have their influence. Thus, for instance, an implausible theory could be proposed which is identical to the model proposed by Just and Carpenter except that word decoding occurs only after all other comprehension processes involving that word have taken place. Such a theory would receive equal support from the analysis they present, as would any other model positing a similar set of determining variables.

There are a number of characteristics that a theory of reading comprehension might be expected to possess if it is to be distinguished as a "real-time theory." At a minimum, it should provide a list of factors that enter into real-time duration predictions. In this sense, Just and Carpenter have provided a real-time theory. More importantly, however, a real-time theory should provide for predictions about the ordering of component processes and the manner by which various processes interact. Their theory, as presented, does not provide for this type of prediction.

Just and Carpenter claim that their model could be realized as a fairly complex production system. In actually constructing such a production system, the theory would presumably be "fleshed out" to the point where predictions could be derived, and hence tested by other regression techniques. At the present time, however, the type of analysis they employ simply cannot provide much support for the rather broad theoretical speculations they present. While the model does indeed encompass a large number of issues which are usually not covered by a single theory, their analysis of the eye movement data does not provide a basis for favoring this model over any other model containing similar factors. Such an analysis could only provide support for a particular theory if it included factors which would distinguish among theories of similar scope. The word-level factors in their analysis were number of syllables, log printed frequency, novel word, case role (a set of variables), and three variables that coded the words' location: beginning of line, last word in sentence, last word in paragraph. With the possible exception of the variables coding word location, it would not appear to be a controversial claim that these factors (or their correlates) contribute to processing time in some manner, yet this is the only claim their data support.

<u>Summary</u>

We have argued that eye movement records do not directly provide a measure of processing time. If more were known about specific relationships between cognitive processes and eye guidance, processing time profiles could be constructed from eye movement records in a manner motivated by this knowledge. Lacking this, assumptions must be made in order to construct such profiles. Mean Gaze Durations appear to be inappropriate measures of processing time, and an alternative method has been suggested. Predicting these processing time profiles requires consideration of how a large number of variables interact in a real-time processing situation. Any real-time theory of reading must provide testable predictions which go beyond assertions that particular variables are involved in determining processing time.

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2. McConkie, G. W. Where do we read? Paper presented at the annual meeting of the Psychonomics Society, San Antonio, 1978.

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Footnotes

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[1] We will use terms like "fixate a position" to mean that the eyes are positioned in the same position they would be when a subject is asked to look directly at that position. "Fixate a word" is used to indicate that some position within the word is fixated. We do not wish to imply by this term that a fixated word is read during that fixation, as this is an issue which will be discussed.

[2] We have not exactly replicated their analysis as applied to the measure of processing time proposed here. In our analysis syntactic category (noun, verb, adjective, etc.) was coded instead of case role. For the independent variables that were identically coded, the results were similar in that the variables produced significant effects. The R^2 values, however, tended to be lower than those reported by Just and Carpenter.

Table 1

Summary of Data From Alaska Passage

Word Length	1	2	3	4	5	6	7	8	9	10	>10
Number of Words In Passage	9	50	94	58	49	66	54	17	10	7	3
Number of Different Words Fixated In 24 Readings	33	311	867	873	852	1211	1064	347	216	154	66
Number of Fixations On Words of Various Lengths	33	347	986	1118	1128	1646	1490	511	357	279	137
Fixations Per Word	1.00	1.12	1.14	1.28	1.32	1.36	1.40	1.47	1.65	1.81	2.07
Proportion of Words Not Fixated	.847	.741	.616	.373	.276	.235	.179	.150	.100	.083	.083
Expected Number of Fixations Under Random Model	37	406	1148	945	998	1612	1539	553	366	285	143

Table 2

Proportion of Three Letter Words

Receiving One or More Fixations[a]

FOG	(24)	.750	BUT	(24)	.458
FAR	(48)	.687	NOT	(24)	.458
PER	(24)	.625	HIS	(48)	.396
BUY	(24)	.583	OUT	(24)	.375
NOW	(24)	.583	SET	(24)	.375
DID	(24)	.541	THE	(936)	.370
HAD	(24)	.541	WAS	(120)	.358
MEN	(96)	.521	AND	(480)	.281
SEA	(144)	.514	FUR	(48)	.271
LED	(24)	.500	FOR	(72)	.264

[a]The Number In Parentheses Indicates the Number of Occurrences In 24 Readings.

Table 3

Breakdown of Position of Eye After Saccade

by Length of Word On Right

	1	2	3	4	5	6	7	8	9	10	>10
Proportion of Time Eye Regresses One or More Words	.006	.024	.043	.027	.014	.015	.010	.008	.001	.001	.002
Proportion of Times Eye Remains On Previously Fixated Word After Saccade	.002	.015	.022	.011	.012	.017	.010	.003	.000	.000	.000
Proportion of Times Eye Moves Forward One or More Words	.026	.178	.246	.083	.062	.074	.064	.012	.006	.010	.001
Probability of Advancing Only One Word Given Forward Move of One or More Words	.373	.440	.452	.540	.654	.777	.819	.862	.875	.961	.667*
Probability of Skipping Word On Right Given Forward Move of One or More Words	.627	.560	.598	.460	.346	.223	.181	.138	.125	.039	.333*

*These Figures Are Based On A Small (<18) Number of Instances.

Figure Caption

Figure 1. Sample eye movement data from one subject reading one line. The upper number represents the fixation number and the lower number represents the associated fixation duration.

When white men first arrived in the Alaska region, three groups

1	2	3	4	5	7	6	8
353	190	253	143	300	201	186	299

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