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AUTHOR McConkie, George W.; And Others
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ABSTRACT

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Technical Report No. 134

TOWARD THE USE OF EYE MOVEMENTS IN THE STUDY OF LANGUAGE PROCESSING

George W. McConkie, Thomas W. Hogaboam,
Gary S. Wolverton, David Zola
University of Illinois at Urbana-Champaign

Peter A. Lucas
University of Wisconsin

August 1979

University of Illinois
at Urbana-Champaign
51 Gerty Drive
Champaign, Illinois 61820

Bolt Beranek and Newman Inc.
50 Moulton Street
Cambridge, Massachusetts 02138

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Abstract

Three problems in the use of eye movement data for the study of language processing are discussed: the perceptual span problem, the data summary problem, and the eye-mind lag problem. Recent research on perception during reading is described which bears on these problems. Finally, a general approach to the use of eye movement data for studying language processing is presented, based on present knowledge of perceptual processing and eye movement control during reading.

Toward the Use of Eye Movements in the Study of Language Processing

It is our desire to study the nature of skilled silent reading and to describe the perceptual and language processes that are taking place as reading is in progress. This is difficult to do because there are few outwardly observable indicators of the rich and complex mental activities occurring during reading. Eye movements are one such indicator. While past decades of research on eye movements in reading have not been particularly helpful in understanding the nature of reading, this situation is changing. In fact, we are coming to realize that eye movement research is critical to the investigation of the ongoing processes during reading.

This claim concerning the importance of eye movement monitoring is based on the following argument. In order to study processing as it is taking place, it is necessary to know what stimulus information is being encountered at any given moment in time. This problem can be illustrated by looking at studies of comprehension of oral language. Here the presentation of the stimulus is to a great extent under the experimenter's control. The experimenter can determine approximately when a given part of the auditory signal will strike the listener's ear. While there is some indeterminacy in knowing just when a phoneme begins and ends, or when a word can be said to have been perceived, there is still sufficient access to and control over the stimulus to permit the placement of a click at a specific location in the speech stream, or to measure the response time from the occurrence of a particular phoneme. Knowing when specific aspects of the stimulus are encountered provides a basis both for making manipulations and for making measurements with respect to certain aspects of the stimulus, when studying language processing.

In reading, however, the text is physically present at all times, and the reader controls the sequence and timing of its encounter. Thus, it is more difficult to know exactly when contact is being made with a particular letter or word, in order to make manipulations or measurements with respect to it. Eye movement recording is the most likely candidate for providing such information. For example, we may examine eye movement records to learn how much time passes after a person encounters an error in the text before he/she responds to it in some way, such as by making a regressive eye movement. Or we may use eye movement information as a basis for presenting some auditory signal (for instance, a word or click) as the subject is reading a particular word in the text. For many purposes the monitoring of eye movements is a basic technology for the further study of ongoing processing during reading.

A second important use of eye movement monitoring is as a source of data. More and more evidence is accumulating to indicate that where the eye is sent and how long it remains at each location is specifically controlled and reflects various aspects of the mental activities of the reader (Rayner, 1979; Levy-Schoen & O'Regan, 1979). The use of eye movement records as a source of data will be discussed further and illustrated later in this paper.

First, however, it is important to note some of the problems involved in using eye movement information for either purpose (i.e., for experimental control or as data) aside from the technical problems of obtaining accurate records. The problems include the following:

1. The perceptual span problem. Eye movement records directly indicate where the eye was centered for a given person on a given fixation. They do not by themselves indicate what region of text was seen during that fixation (or whether any text was seen, for that matter). Thus, while the record may indicate the general region from which visual information is probably being obtained during a fixation, it does not indicate on which fixation or fixations a given word is being encountered. As an example of a situation in which this problem arises, an experimenter may believe that the time a person requires to press a button when a click sounds provides an indication of the person's cognitive load at that moment in time. The experimenter may have a hypothesis that the reader's cognitive load is greater at one place in the text than at some other place because of a difference in the language processes believed to be occurring at those points. To test the hypothesis, the experimenter wishes to sound a click during the fixation on which particular words are being seen. Only with greater understanding than we currently have about perception during fixations can eye movement information be used accurately for such a purpose. There is a parallel problem in data analysis, as discussed next.

2. The data summary problem. Theories of language processing often make predictions about the relative amount of processing time required at

different points in the text. Eye movement records seem like a natural source for such information. For instance, one may wish to test the hypothesis that the primary meaning of a word with several meanings can be accessed faster than the secondary meaning (Hogaboam, 1978). If this is so, one should be able to observe shorter fixation durations on such words when the context calls for the more common meaning. However, without knowing exactly which region of text was being seen on a given fixation, it is not possible to reliably identify the fixation on which the word of interest was encountered. In fact, it is possible that the word was seen on more than one fixation during the reading. This makes it difficult to know just which fixation durations to use in the data analysis in order to provide a clean test of the hypothesis. This problem is compounded even further by the next problem.

3. <u>The eye-mind lag problem</u>. While the above problems have addressed the difficulty of knowing on which fixation a given word is being encountered, there is a further problem of knowing when the effects of the processing of that word will be reflected in the eye movement pattern. If ambiguous words do have the effect hypothesized above, will the greater processing time be observed on the very fixation on which the word is visually encountered, or does the meaning identification for that word occur only at some later time? For instance, if meaning identification is delayed for 300 msec, the reader will probably have made one or two further fixations, and hence be looking at some other word in the text. An increase or decrease in processing time would only be seen in later fixations. Thus,

in order to know where in the data record to look for a longer fixation duration, or when to produce an experimental manipulation that is to occur simultaneously with a particular mental event, it is necessary to know how long following visual perception of a word the mental operation of interest is actually carried out. Research on the eye-voice span in reading indicates a substantial time (Geyer, 1968, suggests one second) between the perception and the vocalization of words in reading aloud. Of course, it could still be that the understanding of the word occurs almost immediately upon its perception, with only the vocalization being delayed (we will later suggest that this appears to be the case in reading). For the present it is sufficient to point out that this lag between visual encounter of information and the carrying out of higher mental activities involving the use of that information is a problem that must be addressed before eye movement data can be wisely used to test hypotheses about language processing.

Thus, while eye movement data offer promise for playing a central role in the study of language processing in reading, there are some prior questions about perception and eye movements themselves that must be resolved first. These are the questions of what is seen during a fixation, when it is seen, when this information has its effects on comprehension, and how the mind determines when and where to send the eyes. Different answers to these questions would lead to different inferences about reading based on the same set of eye movement data. For instance, if the eyes are simply being sent random distances along the line during saccades, specific eye position information is not likely to be useful in testing theories of language processing. But if the eye is being sent to a preplanned location on each eye movement, eye position information may be very useful for this purpose. It is to research on these questions which we now turn.

Some Studies of Perception During Reading

Is the Eye being Sent to Specific Locations During Reading?

There has been considerable speculation that it matters little where the eye is sent during reading, and that there may be little specific control of eye movements other than insuring that the eyes are proceeding down the line of text at an appropriate rate to provide visual input for reading (Bouma & deVoogd, 1974; Shebilske, 1975). If this were true, we would not expect eye movement data to yield much specific information about the processes involved in reading. To investigate this question, McConkie, Wolverton, and Zola (Note 1) shifted the entire line of text two letter positions to right or left during certain saccadic eye movements as subjects were reading. This caused the next fixation to be located at a slightly different place in the text than would normally have been the case. The question was whether this would have any effect on the reader. There are two results to report from this study. First, the readers were unaware that the text had moved. Second, however, this manipulation had a definite effect on the eye movement pattern. A shift to the left, which placed the next fixation two letter positions further into the text than would normally have been the case, caused a large number of short regressive eye movements of two to three letter positions in length. A shift to the right, which caused the eye to fall short of the location to which it was sent, reduced by half the number of regressive eye movements which normally occur. Thus, it can be concluded that the eyes were being sent to a specific location; arriving at a position only two letter positions away had a definite effect on the normal reading pattern.

Is the Text being Seen During Saccades, or Only During Fixations?

The answer to this question will indicate whether the subject may be encountering words as the eye is in flight, or whether this occurs only during fixations while the eye is relatively still. Thus it may influence when an investigator should make stimulus manipulations, if they are to co-occur with the perceiving of a word, for instance. Wolverton (Note 2) investigated this question by causing the line of text to be replaced by some other line for up to 30 msec during certain saccades. He then examined the durations of the next two fixations, and length of the next saccade, to determine whether there was any evidence of disruption. This manipulation had no significant influe on the reading pattern. Our subjective experience with this manipulation is that when the text is blanked out during the saccade this is highly noticeable and is perceived as an abrupt flicker. However, replacing one line of text by another, or by a string of X's, is not noticed by the reader. Thus, it appears that the reading of the text occurs only during fixations. This means that many types of changes in the text can be made during saccades without the subject noticing the simple occurrence of change (for example, see McConkie & Zola, 1979). If the change is detected, it is because a difference is noticed in the pattern from one fixation to the next. It also means that the experimenter, under most circumstances, need not be concerned with information being acquired during saccadic eye movements, and can deal only with vision during fixations.

When During a Fixation is Visual Information being Acquired?

While it appears that readers pick up language information from the text only during fixations, this still does not indicate when during the fixation such information is acquired. Does this happen only at the beginning of each fixation, with the remainder of the fixation time devoted to language processing activities, or is visual information acquired and used as needed throughout the fixation? Wolverton (Note 2) continued the study just described by replacing the line of text with some other line for a 30 msec period at different times during certain fixations: either as soon as the fixation began, or 30, 100, or 200 msec after its beginning. The replacement line was either the original line of text (as a control condition), or a line of blanks, of X's, of some totally unrelated line of text, or a line of letters each selected as the letter most visually similar to the original letter in the text. The X's and unrelated line of text had the largest effect, causing an increase in the duration of the fixation during which the manipulation was made. Blanks and similar letters had less effect. However, the point of interest here was that such effects were found when this replacement occurred at each of the times during the fixation. Thus there is no point during the fixation at which the visual system is insensitive to the textual stimuli because of saccadic suppression or because visual input has been completed. It appears that the acquisition of visual information is likely occurring throughout the fixation, as needed to support language processing.

There is a related observation which we have made several times during pilot studies. We have had subjects read text in which either of two words, differing in a single letter, would be appropriate in a certain word position (for example, brain and brawn). Eighty msec after the onset of each fixation, the text has been masked by a 20 msec presentation of a row of X's, or has been shifted one letter position to right and then left. The text then reappeared but with the critical letter changed. Thus, one word was in that location during the first part of the fixation, and a different word during the latter part, with a general perturbation of the text in between, which reduced the obviousness of change at the critical letter position. Following reading, the subject was asked a question, the answer to which would indicate which of the two words had been seen in that word location. Sometimes the subject has reported seeing only the first word presented, sometimes only the second, and sometimes has reported seeing both words. This suggests that a given text region is sometimes read during the early part of a fixation, and sometimes during the latter part. Thus it seems likely that visual information is being used from different text regions at different times during the fixation, as needed for the language processing of the moment.

<u>Is Visual Information from the Same Textual Region being Seen on More than One Fixation?</u>

Smith (1971) suggested that during reading the person sees the same word on more than one fixation, and that this contributes to accuracy in reading. Bouma (1978) has suggested that information acquired from the visual peripheral regions during one fixation, and corresponding information from the central visual region on the next, reach the brain at about the same time, thus reinforcing each other and enhancing perception. To test this, McConkie (Note 3) identified pairs of words which differed in a single letter. These were five letter words differing in the fourth letter (<u>brain</u>-<u>brawn</u>, <u>leads</u>-<u>leaks</u>, etc.). Sentences were prepared in which either word was appropriate. Then subjects read these sentences as their movements were being monitored. During each forward saccade which t elled at least three letter positions, the letter distinguishing the two words was switched. Thus, one word appeared in the sentence during one fixation, the other during the second, the first word during the next fixation, etc. The subjects were completely unaware that any change was taking place, and were able to report the word they had seen in the sentence. Furthermore, this changing of words had no effect on the readers' eye movement patterns. Thus, it appears that a particular letter is being identified on only a single fixation, with the possible exception of cases where a subject regresses back to a word after having read it earlier. If this conclusion continues to receive support, it simplifies the use of eye movement data in reading research. It justifies the notion that there is a particular fixation on which a letter, letter group, or word can be said to be perceived. If the same text region was being seen on several successive fixations, it would be much less clear just which fixations should be considered critical to the perception of that region.

<u>What Region of Text is being Seen During a Fixation?</u>

The finding that subjects are acquiring information from a given letter position during only a single fixation places severe constraints on the size of the region from which visual information is being used during a fixation. Since the average length of saccades during reading is about 8-10 letter positions, even with good readers, we are inclined to believe that this is about the size of the region being seen during a fixation. McConkie and Rayner (1976) found that replacing text more than four letter positions to the left of the fixation point during each fixation had no adverse effect on the subjects' reading behavior; it appeared that visual information in that region was not typically being used for reading. Apparently reading is taking place to a greater distance to the right of the fixation point than to the left, a point which has received additional evidence in another study (McConkie, Note 3).

One reasonable possibility is that readers typically cast their eyes to a position near that to which identification was successful during the prior fixation (McConkie, 1979). Further research is exploring this possibility at the present time.

While much more research is needed on this question, it appears that during a fixation in reading, the subject is acquiring visual information from a relatively narrow region of text, the size of which may vary from fixation to fixation, but which lies asymmetrically to the right of the center of vision and which may be indicated by the locations of the present and next fixations.

Do Language Constraints Influence What is Seen During a Fixation?

There has been much written about how language constraints permit the reader to identify words or meanings in the text with the use of less visual information, thus allowing reading to occur at higher speeds. Primary evidence for this position has been the work of Tulving and Gold (1963) and Morton (1964) who have shown that the visual duration threshold for words can be greatly reduced by giving appropriate prior linguistic context. This theme has been picked up by many writers who have suggested that readers form hypotheses or guesses about the language which they will next encounter in the text, and that only minimal visual information is then required to confirm or disconfirm these guesses. Under high constraint conditions, very little visual information should be needed.

Zola (Note 4) has explored this question by developing paragraphs in which the predictability of one word in the text depends on which of two words precedes it. In one instance, for example, a passage about a theater speaks either of buttered popcorn or of adequate popcorn. In norms previously gathered, it was found that when the highly constraining word was present (e.g., buttered), people guessed the next word (popcorn) with accuracies averaging over 85%. When the low constraining word was in that location (e.g., adequate), the target word was guessed with accuracies averaging less than 15%. Thus, in reading, much less visual information should be needed from the target word under the high constraint condition, if readers are making and confirming hypotheses as suggested. To test this, another group of subjects read one or the other of these two versions of each passage while their eye movements were being monitored. (No stimulus changes took place during the reading in this experiment). The first question was whether subjects would be less likely to fixate the target word when it was highly predictable. This was not the case. Under high constraint conditions, 98% of the subjects fixated the target word, and under low constraint conditions, 96% did. Thus, subjects did not skip over the word when it was highly predictable. The second question was whether less time was spent on the word when it was highly constrained. Here it is necessary to distinguish between total time spent fixating that word during reading vs. the fixation duration of the first fixation on the word. Less total time was indeed ~~spent on~~ the word in the high constraint condition, a difference of 23 msec. This difference appears to come primarily from a reduced likelihood of regressing back to the word after having read it earlier. The durations of fixations on the word as it was first being read also show a small advantage for the high constraint condition, a difference of 9 msec. Thus, a large difference in language constraint does appear to produce a small difference in the duration of a fixation on that word in the text.

Zola then went on to test whether less visual information was being used from the target word under high constraint conditions than under low. He did this by placing errors of various degrees in the target word. The smallest error was to replace the fourth letter with the letter most visually similar to it. This consisted, then, of a very small change in the visual configuration made at a highly redundant location in the center of a word. There seems little question but that this change involved visual information that is not required for word identification under high constraint conditions. However, even this minimal error had an effect on reading: it increased the average duration of fixations on the word by 20 msec (as compared to 25 msec under low constraint conditions), increased total time spent fixating the word by 63 msec (as compared to 125 msec for low constraint conditions), and increased total reading time for the line by 125 msec (as compared to 261 msec for the low constraint condition). Thus, this study provides no evidence that even the most minimal error in a word is passed over during reading under extremely high redundancy conditions. There is no evidence here that the reader is essentially anticipating what is to come next and then acquiring only the visual information necessary to confirm or reject the prediction. Instead, the reader appears to be responding to the full visual detail of the text in the act of reading, even when that detail may not seem necessary from an information theoretic point of view.

<u>How Much Lag is there Between the Time Information is Visually Encountered and the Time When it is Used for Reading?</u>

A number of people have suggested that there may be a buffer of some sort into which information is being placed as a result of visual analysis of the text, and from which the language processes can then draw as needed at some later time (Bouma & deVoogd, 1974; Shebilske, 1975). If this were the case, the text being understood at any particular moment in time would not be that which was being visually perceived. It also seems possible that there may be a series of stages in which the information is used for making successively higher integrations of the word or words which permits the perception or construction of that meaning and that there may be some delay before the final stages are reached. For the present purposes, we will simply focus on the question of whether such a considerable lag occurs, since this has important implications for the use of eye movement data. If there were a large lag, the effects of language processing stimulated by one part of the text would only be observed as the person was looking at some other part of the text, one or more fixations later. This would make the use of eye movement data much more difficult. This is essentially the eye-mind lag problem mentioned earlier.

This question cannot be answered definitively at the present time. A partial answer, however, can be given. It is clear that manipulations of the visual stimulus can have an immediate effect; that is, the effects produced by stimulus manipulations in the studies described earlier are typically seen on the duration of the fixation on which the manipulation occurs, or on the saccade immediately following. Rayner (1975) changed the contents of one word position during a saccade and found that this inflated the duration of the fixation on which the changed word was first encountered. Wolverton (Note 2), as reported earlier, found that replacing text with some other line for a 30 msec period inflated the duration of that fixation. McConkie, Wolverton, and Zola (Note 1) found that moving the text a short distance during a saccade affected the probability of the next saccade being a regression. Thus, such stimulus manipulations as these have an effect which occurs within the period of a fixation.

Though less well established, it appears the characteristics of words can influence the duration of the fixation on which they are perceived. It has commonly been reported that numbers and less common words tend to produce longer fixations (Woodworth, 1938), observations which we have also replicated. O'Regan (1979) reported a tendency to skip the word <u>the</u> during reading sentences with certain syntactic structures. However, as Levy-Schoen and O'Regan (1979) point out, this evidence is less convincing because it is possible the word was perceived peripherally on the fixation prior to that on which the effect was observed. While this possibility remains, what we have learned about the size of the perceptual span makes it appear highly probable that the variables were having their effect on the fixation during which the critical text region (the word or number) was being perceived.

Finally, at present there is practically no evidence concerning the amount of delay before higher-level processing takes place (for instance, before the semantic relation between a verb and its direct object is perceived, before the referent of a pronoun is established, or before the relation of the information in one sentence to prior information is identified in normal text). Isakson (1979) provides some evidence that semantic integration can occur very rapidly, and Danks and Fears (in press) presents data on oral reading that suggests that some forms of integration occur prior to others. Still this remains an important question needing study before we can have full confidence in using eye movement records for the study of these aspects of language processing in reading.

The Study of Language Processing

In this section, we will attempt to describe a way of conceptualizing the relationship between eye movements and language processing which seems compatible with findings from the research described above (McConkie, 1979). While it cannot be claimed that existing research has strongly supported this view over competing possibilities, this approach does seem to be in harmony with the observations made so far, and it helps clarify just what information eye movements might contribute to our understanding of language processing. In addition, two examples are provided of studies which investigate questions of language processing using eye movement data.

How do Eye Movements Relate to Language Processing?

It is assumed that the reader is primarily involved in the attempt to understand and remember the concepts and relations being expressed in the text. In support of that activity, visual information is acquired as it is needed during the fixation in order to make the identifications, discriminations, and/or decisions that are required, and that can be based on the visual information. Thus, visual information is taken, not from some buffer, but directly from input from the retina as it is needed throughout the fixation, with information used from different regions at different times.

At some time during each fixation, visual information is sought from a retinal region from which the needed level of detail is insufficient for the present purpose. It is this event which triggers a saccadic movement. The eye is simply rotated the direction and distance required to cause the region from which visual detail is being sought to lie on the fovea, closer to the center of vision. Just where the eye tends to be centered with respect to the location of the needed visual information is a question requiring further study, but it appears to be centered rather close to it. Reading then continues along the line from that point during the next fixation. Thus, there is little overlap from fixation to fixation in the region from which visual detail is taken and used for reading, and this region tends to extend primarily to the right of the center of vision. In the event that difficulty is encountered, a reconsideration of previously read text may be necessary. Again, if the region from which visual information is needed is sufficiently far from the center of vision that the level of detail required is not readily available, a regressive eye movement will be initiated.

At what point the level of needed detail will be insufficient will vary with a number of variables, such as the redundancy of the language at that point in the text, just which alternatives must be distinguished at that point, the reader's experience in using the redundancies in the language in reading, etc. This assumes that contextual information can assist in the identification of a word in peripheral vision, permitting identification when less than the full visual detail is available, and that just what detail is needed depends in some way on alternative words that would be appropriate in the context. Thus, although the mechanism for eye movement control may be simple, with the eye simply being sent to the region from which visual detail is sought but is not readily available, in fact, the lengths of saccades reflect characteristics of the language and the reader's knowledge and skill. This way of thinking of eye movement control suggests that the eye movements are under precise control, but that this control is not based on predictions, nor on any sort of "preattentional" analysis of peripheral information used to decide where the information-rich regions will be in the text. On the other hand, the eye movement patterns do reflect language processing in a detailed way.

If the basic assumptions of this view of eye movement control are generally correct, then it follows that eye movement records provide two types of information that may be of use in understanding language processing. First, the location of each fixation indicates the place in the text from which visual detail is being sought at the beginning of that fixation (and at the end of the prior fixation). Thus, the eye serves as a marker, placing benchmarks (fixation locations) which intermittently indicate just where visual information is being sought. Of course, the eye movement record by itself does not indicate where visual information is being sought at other times, just as benchmarks do not indicate the elevation of the terrain between two markers. However, further research should produce some general principles concerning this. Second, the eye movement record indicates how much time elapses between the seeking of information from these specific locations. This information is given by the fixation durations, which can typically be taken as the time required for carrying out the processing, to some as yet undetermined level, using the visual information acquired during that fixation. This qualification, "to some as yet undetermined level," reflects our lack of knowledge about the speed with which this processing occurs (part of the eye-mind lag problem mentioned earlier).

From this brief description, it can be seen that we expect the eye movement record to provide useful information about the time required for language processing activities of various types to be carried out, and information about when the reader seeks visual information in other than the normal left-right sequence of reading. We will now provide two examples of the use of this information, and then describe a general approach to the problem of analyzing eye movement data in a manner which will be useful for testing theories of language processing.

The Identification of Ambiguous Words During Reading

One aspect of language processing during reading concerns the way in which meanings of words are aroused and/or selected. Much of the research on this problem of lexical access has involved words which have more than one distinct meaning, such as bank (financial institution, land alongside a river, a maneuver made by a flying object such as an airplane). When such a word is encountered, are all meanings aroused and only the appropriate one selected for use (Foss & Jenkins, 1973), or does the presence of context invoke some procedure by which only the appropriate meaning is aroused? Results involving recognition or recall tests tend to indicate that only the contextually appropriate meaning is encountered. Studies involving phoneme monitoring tasks find longer response times for such ambiguous words regardless of context, suggesting retrieval of multiple meanings. Hogaboam (1978) investigated this question using a task in which the ambiguous word was the last word in a paragraph, and the subject was to press a button as soon as the meaning of the word was understood. He found evidence of faster responding to the word when the culturally most frequent sense was the appropriate meaning in the context. This finding was taken to indicate that the primary meaning is first aroused, and the secondary meaning is then aroused, only if the primary meaning was contextually inappropriate.

Hogaboam (Note 5) replicated part of this study, having subjects simply read the passages as their eye movements were monitored. He examined the eye movement data to see if the time required for processing the ambiguous words differed according to which meaning the context demanded. Fixations which centered on the ambiguous word itself averaged 36 msec longer when the secondary meaning was required than when the primary meaning was required. Thus the pattern found in eye movement records supported the earlier pattern from the response time task, and provided additional support for the hypothesis that secondary meanings of words are accessed only after primary meanings have been aroused and found inappropriate.

One aspect of these data also bears on the question of eye-mind lag. It is of interest that the increment in fixation duration is found for fixations centered directly on the ambiguous words themselves, the fixations on which the words were probably identified. Thus, the data suggest that the use of context to select the meaning of an ambiguous word was occurring during the fixation on which the word was first identified. This aspect of language processing appears to occur with very short lag.

Is there an Independent Comprehension Component in Understanding a Sentence?

Levelt (Note 6), in his review of the sentence perception literature, has pointed out that many studies dealing with sentence comprehension make the assumption that there is some initial, task-independent stage in all such tasks during which the sentence meaning is initially comprehended. He called this the Immediate Linguistic Awareness (ILA) hypothesis. Theories of sentence verification, for instance, account for the effects of variables (match vs. mismatch of sentence voice, for instance), not in terms of time to comprehend the sentence, but in terms of time to make mental manipulations of that content once the sentence is initially comprehended. While this makes theorizing simpler, it is not clear that the assumption is justifiable.

The testing of the ILA hypothesis was a goal in a study by Lucas (Note 7). In his study, subjects read a first sentence ("A salesman approached a customer.") and then read a second sentence (for instance, "A customer was approached by a salesman." or "A salesman was approached by a customer."). Following reading, they pressed one button if the second sentence was true with respect to the first, and a second button if it was not. Response times indicated that subjects respond faster when the two sentences match in meaning than when they do not (that is, "true" responses are faster than "false"), and that responses are faster when the voice of the two sentences match (both active or both passive) rather than mismatch (one sentence is active, the other is passive). This pattern of results is typical of prior studies and has been accounted for by theories describing the effects as post-comprehensional in nature. In this study, however, subjects' eye movements were also monitored. This made it possible to observe the time spent in reading the second sentence, allowing the determination of how much of the added time was due to slower reading vs. added "thinking time" following the reading.

The eye movement data for "true" instances (those instances in which the meanings of the two sentences matched) was broken down into that portion prior to reading the last phrase in the sentence (called <u>initial reading data</u>), and that following the reading of that phrase (called <u>rereading data</u>). Initial reading data corresponded to the initial scan of the sentences. Each of these was further broken down into time spent fixating the first noun phrase, the verb phrase (with data from passive sentences adjusted for phrase length), and the second noun phrase. The results show that even in initial reading data, when the sentences differed in voice, subjects spent more time fixating the first noun phrase and the verb phrase (each averaging about 55 msec more time), as compared to data when both sentences were either passive or active. Subjects also spent about 98 msec more time fixating the second noun phrase during initial reading when the sentence voice did not match. However, it is impossible to divide that time into initial sentence comprehension vs. postcomprehension activities. Thus, it is clear that part of the added time produced by the mismatch condition is taken in slower reading of the sentence, indicating that at least the strong form of the ILA hypothesis is not an appropriate assumption. At the same time, the mismatch condition also increased the time spent following initial reading of the sentence, before the button was pressed. This time was increased by 298 msec. Thus, part of the increased time was indeed taken following the initial reading of the sentence, and was apparently spent in some sorts of computations involved in matching the meanings of the two sentences, as the post-comprehension models suggest. This latter result supports the position that, in this task, sentences are stored in a form related to the surface form of the sentence, rather than simply representing the meaning relations asserted.

A General Approach to Use of Eye Movement Data

While much of the research described above has focused on the perceptual processes occurring during reading, a motivating force behind it has been the desire to gain the information necessary to use eye movements in the study of language processing. This section will describe a general approach to this problem based on what has been learned about perceptual processes so far.

It is assumed that different parts of a text require differing amounts of processing time. Such differences arise from many sources. Some are the result of the degree of complexity of mental activities required for achieving an understanding of the relationships directly expressed in the text. Some are due to differences in syntax, word frequency, etc. Some are the result of the inferences or other higher level processes stimulated or required by the text. Some are the result of the reader's knowledge or lack of knowledge about the topic under discussion, while others are the result of the task in which the reader is engaged, that is, what information the reader is attempting to understand and retain.

When the different factors that influence processing time are controlled to some extent, there should exist some basic similarities between subjects reading the same text. Thus, we can expect, among a group of readers with similar backgrounds who are reading for a similar purpose, some agreement in what parts of the text will require more and less processing time. If this relative amount of time required for each segment of text were known, this information could be represented by a contour over the text, where the height of the contour indicated the amount of time required for processing that part of the text. This will be called the idealized processing time profile. An example of such a hypothesized profile is shown in Figure 1. Since theories of language processing

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Insert Figure 1 about here

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typically yield predictions of where in the text processing demands will be heavy or light, some approximation to the idealized processing time profile for a given passage could be used to test the adequacy of competing theories of language processing. Since eye movement data appear to reflect processing time allocated to different portions of the text, it seems reasonable to attempt to derive from eye movement records an approximation to the idealized processing time profile for any given passage read under particular circumstances.

There are significant problems in attempting to do this. First, as noted, eye movement data do not directly yield a continuous record. Rather, they provide only intermittent data. If the assumptions described earlier are correct, the duration of a fixation indicates the time spent processing (to some level) the information lying approximately between the locations of two successive fixations when the subject is processing in a normal rightward manner along the line. Still, eye movement records do not indicate the relative amount of time spent on different parts of that region. Second, different people do not fixate at the same locations. Thus, it becomes difficult to know how to combine the data across subjects in order to obtain some sort of average processing curve.

One approach to dealing with these problems and deriving a processing time profile is as follows. Begin by considering a certain region of text as being processed during a fixation. This region will be called the processing span and may or may not be the same region as the perceptual span for that fixation. However, for the present time we will assume that it is the same. The basic assumption here is that each segment of text provides information that is used in interpreting the text. The interpretive processes that are licensed by each segment of text differ for reasons noted above, but the processes that do occur take time and this time is indexed by the fixation durations. The fixation durations may reflect processes specific to the segment being processed as well as higher level integrative processes licensed by that segment. Ideally we would like to assign the fixation duration times to exactly those portions of the text that were being processed on each fixation. As we have made the simplifying assumption that the area being processed is the same as the perceptual span, the fixation duration time will be allocated to, and spread over, this area. Since it is not known where in that region more or less time was taken, the best strategy is simply to spread the time evenly over the region. One convenient way of doing this is to divide the fixation duration by the number of letter positions in the processing span, and assign the quotient to each letter position in the region. This is not to claim that processing is letter-by-letter, but simply to use letter positions as a metric over text space for the present purpose. This can be done with any assumption concerning the processing span, considering it to extend a fixed distance to left and right of the fixation point, or a relative distance based on the lengths of saccades. A number of such possibilities for the processing span have been considered by Hogaboam (Note 5), including the possibilities of fixed vs. variable spans and overlapping vs. non-overlapping spans. For the present, in line with the foregoing comments, it will be assumed that the span is non-overlapping, and that it extends from the locus of one fixation to the locus of the next when bounded by rightward saccades. At present we do not know enough about the characteristics of perception during fixations preceded or followed by regressions to know how to assign these times to the text. This must remain a matter for future research. For the present, time from such fixations must be either ignored or spread over an arbitrary interval to the right and left of the fixation point.

This strategy for spreading reading time over the text for a single subject produces a processing time profile which is a step function. Individual subjects' profiles will be different because they fixate in different places. At the same time, there should be some commonality among them, reflecting the underlying processing demands represented by the idealized processing time profile. An example is provided in Figure 1, which shows the individual profiles derived from two hypothetical readers, who fixated different locations in the text, but whose fixation durations still reflect the processing time differences represented by the idealized processing time profile. Hogaboam (Note 5) reports that correlations between the processing time profiles for different subjects reading a single passage are typically positive and significant though low (in the range of .10).

Obtaining an approximation to the idealized processing profile from these individual profiles is then a matter of averaging over subjects to eliminate noise and obtain an approximation to the signal. When the data from two groups of three subjects each were averaged, and the resulting profiles correlated with each other, a correlation of .33 was obtained. This suggests that with more subjects, a stable profile over the text will emerge, showing interesting variability in time required for processing different portions of text. These profiles will provide a useful basis for testing theories of language processing. An example of such a profile, derived from the data from six subjects, is shown in Figure 2.

Insert Figure 2 about here

This approach was used to analyze the data from the ambiguous word study described earlier (Hogaboam, Note 5). Again it was found that when the context required the most culturally frequent (primary) meaning of an ambiguous word, less time was spent on the word than when the less frequent (secondary) meaning was required. For the primary meaning condition, mean time per character over the word itself was 18 msec, and for the secondary meaning condition it was 23 msec.

As a further test of the sensitivity of such processing profiles to language variables, the processing profile over all instances of the definite article the in a 500 word passage was examined. O'Regan (1979) previously reported a tendency for this word to receive fewer fixations than other three letter words, particularly in certain syntactic frames. The processing profile showed the mean time per character position to be 26 msec for instances of the word <u>the</u> in a passage, as opposed to 35 msec per character position for the passage as a whole. Thus, the profile showed less time spent processing instances of <u>the</u> than other regions of similar size in the passage.

The passage used for this test was a historical text about early exploration of Alaska. It included several dates and other numbers. Such information in a history passage is likely to be particularly important, so the mean time per character position for these regions was calculated from the average processing profile. This mean was found to be 75 msec, considerably higher than the average for the passage as a whole. Thus, there is reason to believe that this general approach to the use of eye movement data may be useful for testing hypotheses about where greater and lesser amounts of time are required for language processing which takes place during reading.

Summary

This paper has been an attempt to provide an overview of some recent research into the nature of the on-going perceptual and language processing during reading. We have tried to justify the position that eye movement data can be useful in investigating these questions, to indicate the types of problems which must be solved before such data can be fully exploited for these purposes, and to demonstrate the types of research techniques which have been developed for finding answers to these problems. We have briefly described a way of viewing the nature of eye movement control, and drawn out implications for how eye movements are related to language processing and what kinds of information may be obtainable from eye movement data for the study of language processing. Finally, we have described a general approach to the treatment of eye movement data for use in testing theories of language processing.

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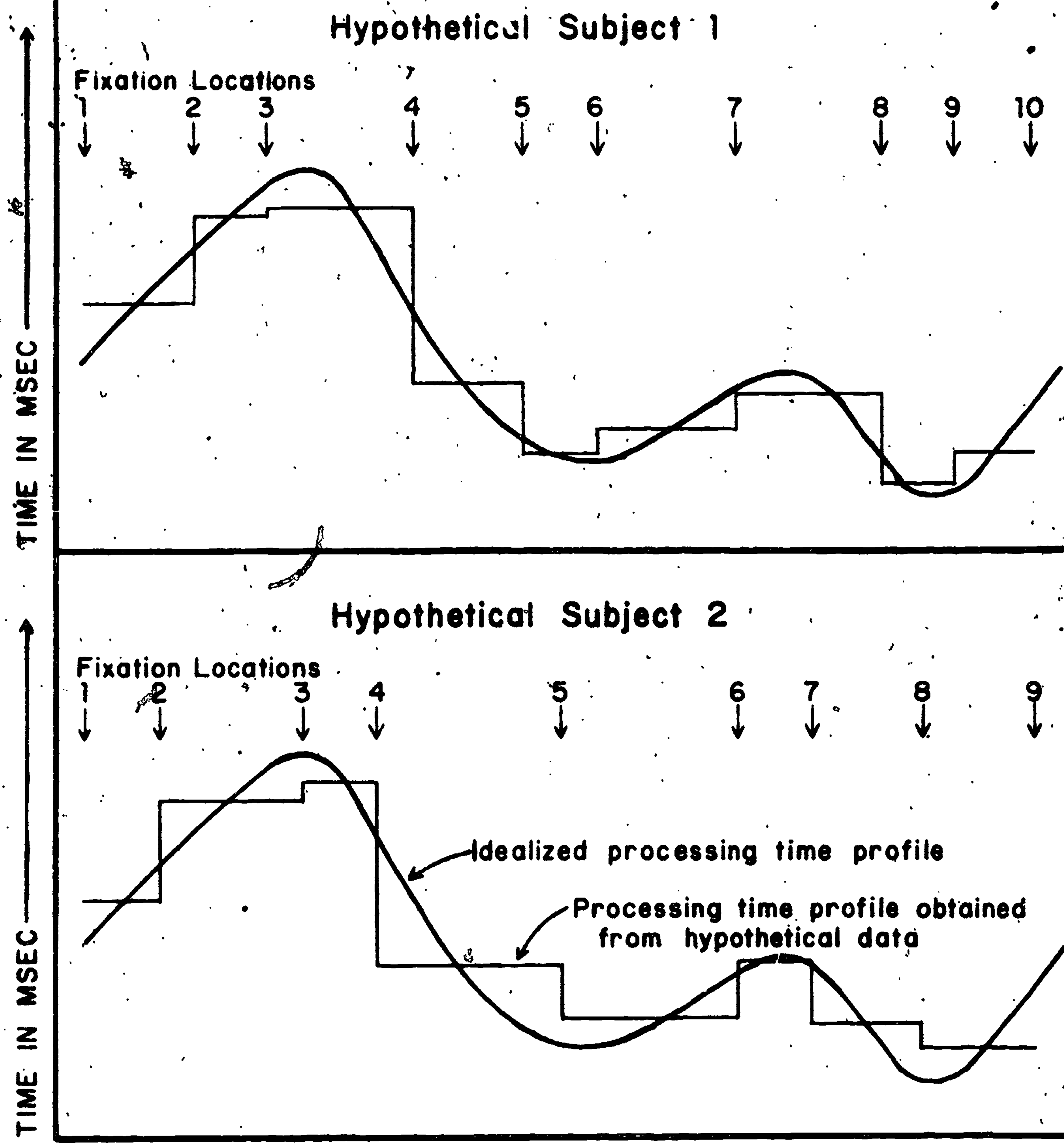
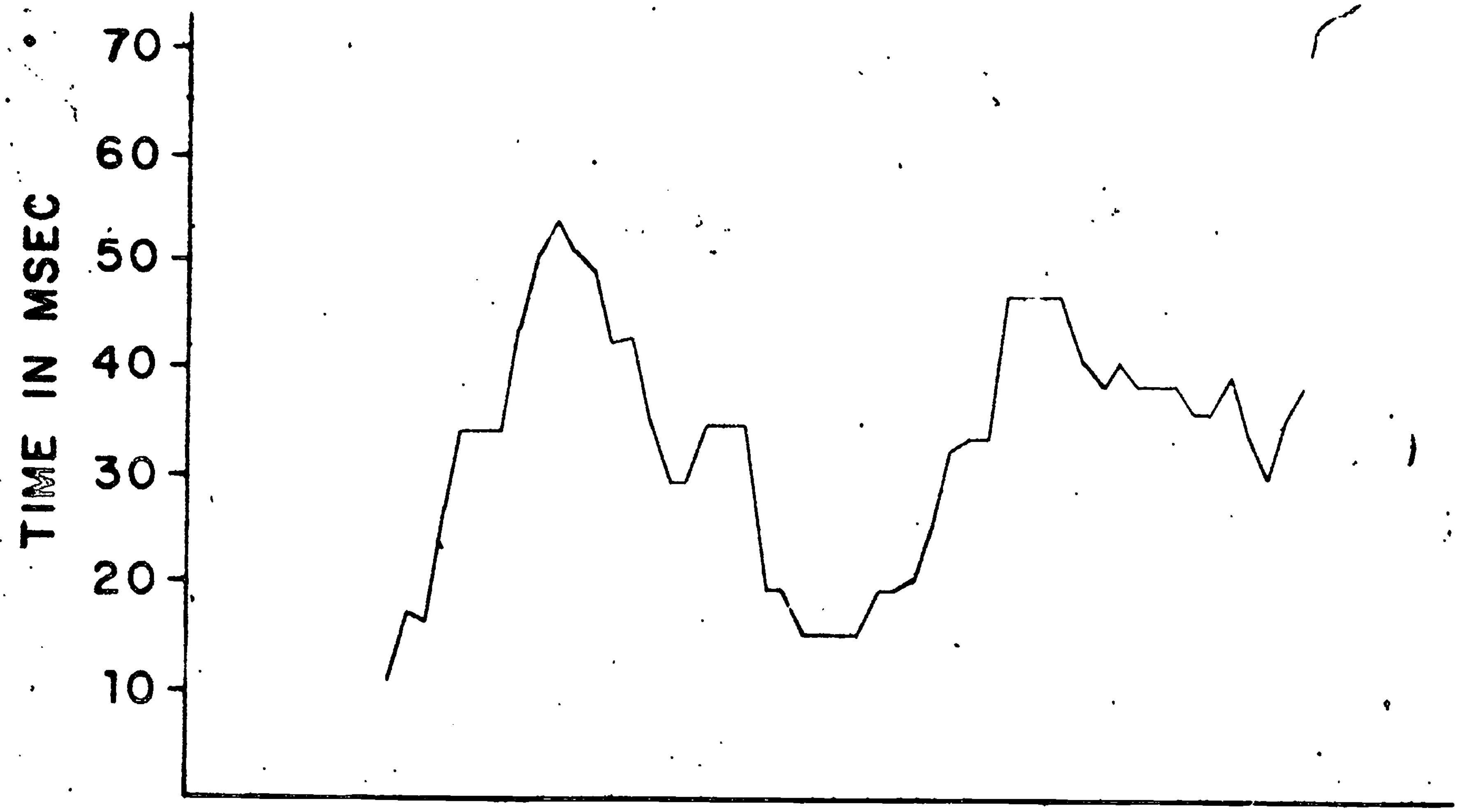
Figure Captions

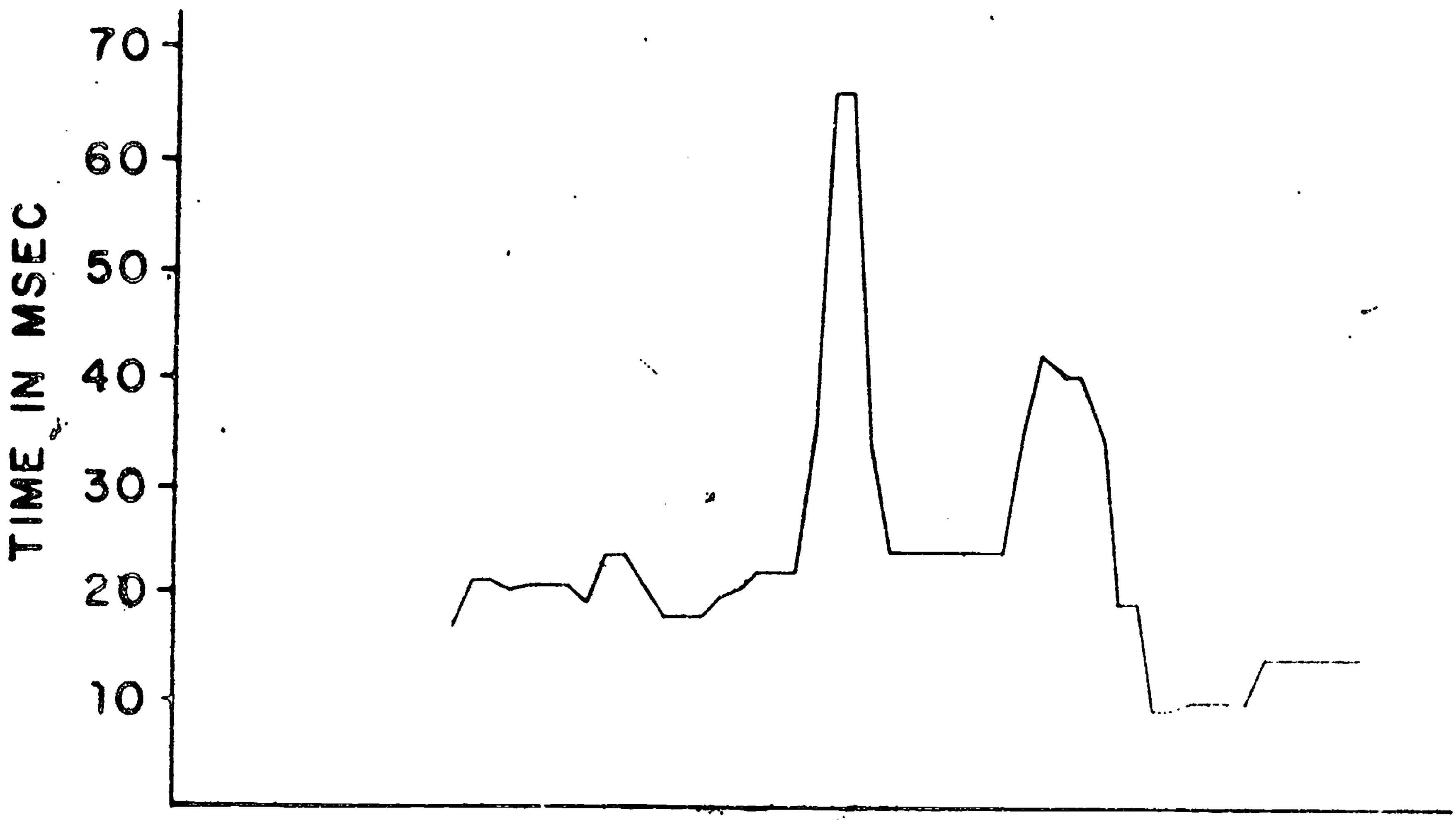
Figure 1. Comparison of profiles from two hypothetical subjects, and the underlying idealized Processing Time Profile.

Figure 2. Processing time profile for two lines of a passage, obtained by averaging the profiles of six subjects.


Hypothetical Subject 1
Fixation Locations
1 2 3 4 5 6 7 8 9 10
TIME IN MSEC
Hypothetical Subject 2
Fixation Locations
1 2 3 4 5 6 7 8 9
Idealized processing time profile
Processing time profile obtained from hypothetical data
TIME IN MSEC



Alaska for the next 68 years. The company treated the Indians



harshly and made slaves of the Aleuts. As a result, the Indians

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