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A TWO STAGE MODEL OF ON LINE PROCESSING
DURING THE READING OF SHORT STORIES

A Dissertation Presented

by

ALBRECHT WERNER INHOFF

Submitted to the Graduate School of the
University of Massachusetts in Partial Fulfilment
of the Requirements for the Degree of

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Psychology

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DURING THE READING OF SHORT STORIES

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My interest in reading research dates back to my studies at the University of Rochester's Center for Visual Science in 1978. I primarily pursued issues in the areas of word perception, integration of information across successive fixations, and masking effects in reading. Keith Rayner and Ralph Norman Haber were the major sponsors of this research.

My interest has shifted somewhat during my studies at the University of Massachusetts. Rather than focusing on perceptual issues, I started to investigate the cognitive representation of words that are presented within a linguistic context. In this way I hoped to understand reader's text comprehension.

Initially I had designed this thesis as an exploration of reader's attention investment during the reading of prose. However, the final form of my thesis has a different emphasis, pinpointing different processing routines during lexical access and word interpretation. This shift in perspective took place in long discussions with my committee. I found all the members of my committee extremely helpful; they facilitated the success of the shift in emphasis.

In addition to my appreciation for the input of my committee I want to thank Chuck Clifton for letting me

use his lab facilities, Sue Lima for reading an early draft of this paper and friends who tried to keep my spirit high when morale was low.

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ABSTRACT

Two experiments were conducted to explore whether readers' on line word processing is affected by lexical and contextual variables. Word frequency (Experiment 1) and factivity (Experiment 2) were manipulated to explore lexical processing. Predictability (Experiment 1) and correctness (Experiment 2) was varied to assess readers' context dependent word interpretation. The results showed that word frequency as well as predictability and correctness manipulations effectively biased readers' fixation time. Low frequency, low predictable and incorrect words received longer fixation times than high frequency, high predictable and correct words. Moreover, a central mask that moved in synchrony with the readers' eyes combined additively with word frequency but interacted with predictablity and correctness. Based on this it was concluded that two autonomous cognitive subroutines affect the on line processing of words during the reading of text; one stage which mediates the processing of individual word characteristics (lexical look-up) and one stage which integrates individual words into the conceptual frame of text.

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CHAPTER 1

INTRODUCTION

During reading, readers fixate individual words as they progress along the line of print. Although individual words are being encountered, the goal of reading is, in general, not a literal but a conceptual representation of text. This accomplishment can be construed as the coordinated execution of a number of processing stages, including visual encoding, lexical look-up, and context-dependent word interpretation. Two of these stages, lexical look-up and context dependent word interpretation, are the focus of the present investigation.

Priming and phoneme detection paradigms have generally been used to explore these two stages. The results showed that individual word characteristics, such as word frequency, and context dependent word characteristics, such as semantic relationship between successive words, affected word processing. Though indicative, these paradigms leave crucial questions unanswered when a theory of readers' on-line text processing is to be developed. Both techniques encounter difficulties when text processing is to be measured in real time. For example, phoneme monitoring techniques measure lexical and contextual effects of

individual target words during the processing of words that follow the target and priming studies in reading use prime-target intervals that by far exceed the stimulus onset interval found across successive saccades.

The present study is designed to complement phoneme monitoring and priming studies in using eye movement records to trace the reader's lexical look-up and word interpretation in real time. Recent research (e.g. Just & Carpenter, 1978; Rayner & McConkie 1976; Rayner, 1978; Rayner & Inhoff, 1981) strongly supports the view that eye movements are a sensitive indicator of readers' on-line cognitive processing performance. Therefore, this thesis will focus on eye movement research, though relevant results, obtained in priming and phoneme monitoring experiments, will be considered as well.

C H A P T E R 2

A TWO STAGE MODEL OF TEXT COMPREHENSION

As already indicated, it appears that at least two stages of word processing occur before a conceptual representation of text can be established. Words have to be identified and the meaning associated with each lexical unit has to be retrieved; this stage has been labelled lexical look-up or lexical access. Furthermore, the reader has to structure words with other words to construct a particular interpretation of individual words that is consistent with prior context. This stage will be loosely referred to as word interpretation.

1. Lexical look-up

During lexical look-up readers are presumably contacting an internal representation that stores (syntactic), semantic and pragmatic properties of individual words (Clark & Clark, 1977). Whaley (1978) presented a comprehensive review of the relative effects of a number of variables upon lexical access. Lexical decision time, which was assumed to be a sensitive measure of lexical access, was found to be affected by a number of individual word characteristics among which word frequency was the most prominent.

Presumably, word frequency affected the time required to access words in the internal lexicon. The more frequent the individual word, the faster it can be accessed.

There is also considerable evidence that indicates that once the lexicon is entered, a comprehensive meaning activation is performed. For example, it appears that, upon entering the lexicon, the processor activates all potential meanings of lexical ambiguities. Foss and Jenkins (1973), using a phoneme monitoring task, found that the presence of a lexically ambiguous word influenced phoneme detection time while listening to words that followed the ambiguity.

Similar results were reported by Cairns and Kamerman (1975) and Tanenhaus, Leiman, and Seidenberg (1979).

Interestingly, these effects were highly limited in time and occurred only immediately after the ambiguity had been encoded. Cairns and Kamerman (1975) showed that ambiguous words yielded effects comparable to unambiguous controls when phonemes were monitored in words that were two words to the right of the critical item. Using the priming paradigm, Swinney (1979) obtained similar results. Lexically ambiguous words were effectively priming target words that were related to different meanings of the prime when the target followed the prime immediately. The small temporal

range across which the effects occurred also accounts for some findings that show that lexically ambiguous words prime only the contextually suggested meaning of the ambiguity (e.g. Swinney and Hakes, 1976). Evidently these earlier studies used prime/target intervals that exceeded the temporal range within which lexical effects could be obtained. Eye movement studies further delineated the temporal characteristics of lexical look-up operations. Just and Carpenter (1980) reported that word frequency was an effective predictor of the cumulated viewing time spent on individual words (Just and Carpenter refer to this measure as gaze duration). However, Kliegl, Olson, and Davidson (1982), trying to replicate the Just and Carpenter data, found only marginal effects of word frequency once word length effects were eliminated.

2. Word interpretation

As already shown, lexical look-up does not necessarily yield a unique word interpretation. Additional processes have to operate so that ambiguous words can be comprehended and so that the particular "flavor" of nonambiguous words can be "tasted" as well (Anderson and Ortony, 1975). These additional processes presumably consist of the reader's formation of a conceptual structure within which ambiguous and

nonambiguous words can be comprehended.

Most of the work done in this area has focused on how context affects the processing of individual words. The data generally showed that readers can respond to individual target words in a semantically related context both more quickly and more accurately, and subjects respond to words in an unrelated context more slowly and with more errors than in a neutral context condition (Fischler & Bloom, 1979; Meyer, Schvaneveldt, & Ruddy 1975; Neely, 1977; Stanovich & West, 1979; 1981). Though suggestive, these studies have strong limitations. Single words or short phrases prevail as primes. Such primes may not have provided sufficient context to establish a conceptual frame of reference; rather, they may exclusively operate at a lexical level by means of built-in lexical associations. However, it should be pointed out that more recent results, obtained with more complex primes and targets, confirm the general pattern found when single word primes were used. For example, Eisenberg and Becker (in press) displayed whole sentence primes and whole target sentences and their results corroborate prior research. Nevertheless, priming studies cannot provide accurate timing of conceptual effects as they occur in reading. In particular, priming studies in reading yield the discussed pattern

of results only when interstimulus intervals (ISI) exceed the ISIs found in reading. The more the prime target ISIs approximated the average fixation duration found in reading, the less pronounced the context effects in priming studies (Stanovich & West, 1981). Thus, there is strong evidence which suggests that readers can establish a conceptual frame of reference within which new words are encoded, the result of which is a more effective text interpretation of related linguistic material. However, a different paradigm seems to be required to trace the temporal course of the effect as it occurs in reading.

Eye movement studies that explored contextual information showed that conceptual constraints can be used on-line, ie. while individual words are being fixated. Just and Carpenter (1977) modified the verb entailment of target sentences; a verb that led to a direct inference (entailment) resulted in shorter gaze durations for the agent of the following sentence than verbs which allowed an indirect inference only. This effect was not observed when the agent was specified first and the verb sentence second. A similar intersentential context effect upon word reading time was reported by Carpenter and Just (1978). Here, target sentences either matched or mismatched presuppositions created in a prior sentence. Matching

and mismatching sentences had identical lexical items, syntactic structures, and logical content; the only difference was the conceptual relation between old and new information. The results showed that the matching factor influenced gaze durations of the critical sentence: Matched sentences required considerably less reading time than mismatched controls. Additional data, obtained by Carpenter and Daneman (1981) agree with these results. In the experiment, prior context primed the interpretation of nonhomophonic homographs either strongly or weakly following text either confirmed or rejected the suggested interpretation. Again there was a strong context effect: Highly primed homographs and confirming text received shorter duration visual inspections than low primed homographs and the contradicting post-homographic text. Similar effects were reported by Ehrlich and Rayner (1981). Context was constructed so that one of two visually similar words was highly constrained by prior context. It was observed that readers occasionally assigned the contextually suggested word interpretation even when the visually similar but semantically discrepant word had been presented. Ehrlich and Rayner also found a strong increase in average fixation durations once the misprimed word was correctly identified.

Eye movement records also reveal a strong influence

of context upon the reader's regressive eye movements, an effect that is particularly striking and deserves special consideration. Carpenter and Just (1978), upon reexamining the Just and Carpenter (1977) findings, reported that readers displayed a greater tendency to regress in the indirect inference condition and spent more time looking back in this condition than in the direct inference trials. Furthermore, Carpenter and Just found that more re-reading time was spent on mismatched sentences than on sentences which had been correctly presupposed (matched), although both conditions were equally likely to initiate regressions. Finally, when a pronoun was ambiguous with respect to the preceding referent, readers tended to initiate regressions to the potential referents. Regessions either commenced immediately after the ambiguous pronoun was encountered or after the whole sentence containing the ambiguity was read. Similarly, Carpenter and Daneman (1981) showed that readers regressed to words that had been misprimed by prior context during the initial reading. An excess of regressions took place when the text following the homograph contradicted the previously suggested homographic interpretation.

3. Lexical access and word interpretation: Two autonomous subroutines?

Both lexical look-up and word interpretation have been found to affect encoding time. These effects may have occurred at the same stages of processing; for example, a global cognitive processor might employ the same processing routines in lexical look-up and word interpretation. Alternatively, individual word characteristics and contextual constraints may have affected two autonomous cognitive subroutines. According to the former view, lexical access is not separable from word interpretation, while the latter position holds that readers use completely different processing routines, one for lexical access and one for context dependent word interpretation. The latter view has been put forth by Foss and Blank (1980). However, it is also possible that readers are more flexible in using their processing routines and do not adhere to two completely autonomous subroutines nor to one global processing strategy; rather readers' lexical access may be biased by contextual constraints and the frequency of lexical look-up may affect the interpretation routines although both operations are associated with different processing routines (Becker, 1979; Rumelhart, 1977).

Recent research has generally supported the notion

of two independent processing structures. Cairns, Cowart and Jablon (1981), using a phoneme monitoring task, found that high predictive context, in comparison with low predictive context, facilitated the detection of target phonemes that followed critical unambiguous words. Cairns et al. attributed the effect to a distinct word interpretation stage that followed lexical access. Faster word interpretation occurred in the high predictive condition "by reducing the amount of discourse relevant information carried by the item" (p. 449). Interestingly, shorter probe latencies in a recognition task were associated with those critical words that had been presented in a low predictive context. Cairns et al. suggested that the more extensive post-access processing, necessitated by the low predictive context, resulted in a more distinctive memory trace which accounted for the faster probe latencies. Results obtained in priming studies also supported the two stage model. Yates (1978) presented homographic primes which were followed either by the dominant or nondominant meaning of the ambiguity. The probabilities were set so that the target in one presentation condition was most frequently the dominant meaning of the homograph while both the dominant and nondominant meaning of the ambiguity followed the target with equal probability in the alternative

presentation condition. There was a facilitation effect of prime presentation only in the former presentation condition. This suggests that subjects were effectively exploiting contextual information only when it provided a reliable conceptual frame for the evaluation of subsequently encoded word information. Other results that used lexical decision time as the dependent measure within the priming paradigm also support the notion of two autonomous subroutines. Meyer, Schvaneveldt, and Ruddy (1975) reported an interaction of prime/target relation with stimulus quality of the target. Stimulus degradation effects were less pronounced under high contextual constraints, i.e. when prime and target were highly related. Word frequency of the target, on the other hand, combined additively with stimulus degradation. Becker and Killion (1977) reported virtually identical results and argued that word frequency affected the stage of lexical look-up while prime/target relationship affected the subjects' expectancies.

Taken together, these data substantiate the claim that autonomous cognitive subroutines mediate word processing. Just and Carpenter (1980), using gaze durations during reading analyzed by multiple regression techniques, further showed that word frequency and contextual constraints may constitute

distinct sources of variance. Thus, lexical access and context dependent word interpretation seem to occur while individual words are fixated. Unfortunately, Just and Carpenter's approach has been criticized for the unit of analysis used; for example, Carrithers and Bever (1982) used individual letters instead of number of syllables as their basic unit of analysis and were able to explain most of Just and Carpenter's "lexical and semantic" variance by means of word length (i.e. perceptual) factors. Similar arguments have been raised by Kliegl et al. (1982). In the present study different units of analysis were used to control for perceptual factors.

C H A P T E R 3
OVERVIEW OF THE EXPERIMENT

The present experiment was conducted to explore the reader's lexical look-up and word interpretation performance as they occur on line during the reading of prose. The goal of the study was similar to that of prior investigations (e.g. Becker & Killion, 1977; Cairns et al. 1981; Just and Carpenter, 1981; Yates, 1978) in that the effects of both stages were explored. In addition, it complemented these studies: first, eye movement measures were obtained so that individual word characteristics and context effects could be assessed on line; second, readers read prose passages which were assumed to evoke conceptual processing routines as they may be used in a variety of reading situations in which readers try to understand complex linguistic information. Thus, the study combined ecological validity with a highly accurate on line measurement of cognitive processes. The study also extends prior eye movement studies (Just & Carpenter, 1980) in that it permitted an independent assessment of the two stages and explored the relationship between them.

In the experiment, lexical access was manipulated by using words differing in frequency of occurrence. As already indicated, prior studies have shown that

high frequency words are accessed faster in the internal lexicon than are low frequency words. Thus high frequency words were expected to receive shorter fixation time than low frequency words. Eye movement studies have confirmed these predictions but they may have suffered from a confounding of word length and word frequency (Carrithers & Bever, 1982; Zuber & Wetzel, 1981).

Word interpretation was assessed by measuring the predictability of individual content words within the conceptual frame of the individual text passages used. High predictable words were hypothesized to be closely tied into the sentence frame and expected to require shorter fixation times than low predictable words.

In addition to manipulating linguistic variables that were assumed to tap lexical look-up and word interpretation, the experiment included a third factor: A small central mask which moved in synchrony with the reader's eyes in half of the trials, completely obliterated the central character (Experiment 1) of text. The mask has been shown to slow down reading rate while leaving the rest of the text legible (Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981). The visual composition of the mask was comparable to that of a pattern mask. It should be pointed out that the

effects exerted by this pattern mask are not equivalent to visual degradations that have been used to tap visual encoding (e.g. Schvaneveldt et al., 1975; Becker & Killion, 1977). This is because the mask left most of the visual array perfectly intact, obscuring only a single segment of text. Furthermore, unlike visual degradation effects, masking effects could not be compensated for by mere passive increases in viewing time, in attempt to gather more visual features; rather, circumventing the masking effects required the readers' active shifting of the mask (by making an eye movement) to release the obliterated information.

The additive factors logic that was used in the earlier studies was applied in the present study. Specifically, masking effects were expected to yield comparable effects upon lexical processing and context dependent word interpretation if comparable processing routines are executed at each stage. On the other hand, the mask was expected to affect both stages differentially if different processing operations are performed at each stage.

Different dependent measures were used to explore the effects. These measures will be referred to as first fixation duration (FFD), initial reading time (IRT) and total viewing time (TVT). First fixation duration only encompassed the very first fixation

placed upon the target words. This measure has been generally favored by Rayner (1977; Ehrlich & Rayner, 1981) and provides precise insight into temporal processing. In particular, the measure was used to explore whether readers establish a conceptual representation of fixated words during the first fixation placed on an individual word. Second, IRTs were calculated to examine the processing time that had to be invested before the next word was fixated. This measure roughly corresponds to Just and Carpenter's gaze durations, in that initial fixation durations spent on individual words were cumulated; IRTs differ from gaze durations in that the measure excluded the time due to intraword eye movements. It should be noted that IRTs and FFDs are identical whenever a particular word receives only one fixation; the measures differ, however, when more than one fixation is placed on an individual target word. Third, total viewing time scores were calculated; these scores consisted of the initial reading times plus the time due to interword regressions to the critical word. A review of the eye movement literature indicates that regressive fixations are particularly closely related to reader's conceptual reprocessing of text.

Finally, two units of analysis were used. In one analysis, the dependent measures were obtained for

whole words. Since this measure may confound cognitive and perceptual variables (Carrithers & Bever, 1982; Zuber & Wetzell, 1981) fixation time/letter measures were also obtained for critical words.

To summarize: In Experiment 1, readers were required to read short passages of prose. These passages were taken literally, or slightly modified, from Lewis Carroll's Alice in Wonderland. Frequency counts allowed an assessment of the reader's word identification performance and predictability ratings served to tap context dependent word interpretation. A small central mask, that moved in synchrony with the readers' eyes was displayed in half of the trials. It was the effect of central mask upon lexical access and word interpretation that was assumed to differentiate between the two processing stages. In particular, processing models that assume different processing routines for lexical access and word interpretation, predicted a differential effect of the mask upon word frequency and predictability; on the other hand, processing models that hypothesize more global cognitive processes predicted comparable masking effects. Different dependent measures were obtained to gain a fine grained analysis of the on-line processing at each processing stage.

CHAPTER IV

EXPERIMENT 1

Method

Subjects. Twelve students from the University of Massachusetts were paid to participate in the experiment. None of the subjects required corrective lenses for reading.

Material. Four excerpts from Alice in Wonderland constituted the experimental passages. Two of them were literal excerpts and two passages were slightly altered so that they constituted small cohesive episodes. The passages were selected for their particular sequencing of events. The excerpts had the characteristic that part of the text conformed to the reader's expectations (see Table 1). For example, upon asking what subjects were taught in school, Alice may answer French and music. Here French and music are in agreement with the reader's knowledge about school curricula. On the other hand, high predictable elements could be followed by unexpected statements. For example, after having asked Alice about her subjects, the interrogator may continue, "How about washing?" Here, although the reader may have been prepared to encounter a question, the particular content of the question doesn't fit the readers' expectations. There is no cognitive structure

Table 1

"we learned French and music"
"and washing?" asked the biber.
"certainly not" answered alice.
"then yours wasn't a really good school
said the biber,
in a tone of great relief.
"now at ours, they had,
at the end of the bill,
french, music, and washing extra."
"and what were the regular courses?"
asked alice curiously.
"Reeling and writhing, of course,
and then the different branches
of arithmetic; for example,
ambition, distraction, uglification."
"never heard of uglification"
said alice quickly.
"never heard of uglification"
exclaimed the biber.
"but I suppose you know
what to beautify is?"

Table 1 depicts a text passage that was used in Experiment 1.

within which the subjects French and washing can be interpreted. At the same time, both predictable and unpredictable information have to be integrated conceptually throughout the story since it is the interplay of expected and unexpected elements that gives the stories their particular (and sometimes peculiar) meaning.

To measure predictability, a sample of 40 to 43 words per story was rated for predictability within the story context. A rating scale ranging from 1 to 10 was devised, with 1 indicating highly unpredictable words and 10 referring to highly predictable words. Thirty subjects served as raters; based on the results, the 15 words of each story that had the highest degree of interrater reliability were selected. The mean values of the selected items served as the criteria for establishing a group of low, medium, and highly predictable words, each group containing five instances per story. The mean predictability values averaged across stories were 2.7, 5.6, and 7.5 for the low, medium and highly predictable items, respectively. In an additional grouping, those five words of the pool of rated words with the highest and lowest frequency counts, and a group of 5 words with medium frequency values (Kucera & Francis, 1967) were selected, forming classes of high, medium, and low frequency items. The

mean frequency scores, averaged across stories, were (1) 5.2, (2) 44.2, and (3) 423.5 for the (1) low, (2) medium, and (3) high frequency words. The corresponding values measured on a logarithmic scale were 0.7, 1.6, and 2.6, respectively. An additional sampling was performed in which highly predictable and low predictable words were assessed orthogonally for high and low frequency words. Low frequency words were those with frequency counts of less than 50 per 100,000; the predictability ratings of low and highly predictable words in this class were 2.7 and 6.8 respectively. High frequency words were those with frequency counts of more than 50; the predictability ratings of low and highly predictable words in the class of high frequency words were 3.6 and 7.1, respectively. Four additional short stories were used as filler passages.

Apparatus. Eye movement recording was accomplished by using a Stanford Research Institute Dual-Purkinje Eyetracker (Clark, 1975; Cornsweet & Crane, 1973). The eye tracker has a resolution of 10 min of arc and the output is linear over the visual angle that was occupied by each sentence (<14 degrees). The eye tracker and a cathode ray tube (CRT) were interfaced with a Hewlett-Packard 2100A computer that controlled the experiment. The signal from the eye tracker was

sampled every msec by the computer. Each 4 msec the eye tracker output was compared to the output of the prior 4 msec to determine whether the eye was fixated or in motion. Display changes, as they occurred in the central mask condition, were accomplished within less than 5 msec after the termination of the saccade was discovered. The impression of all subjects was that the mask moved in perfect synchrony with the eye.

In the experiment, the subject's eyes were 46 cm from the CRT, so that three character spaces equalled 1 degree of visual angle. The stimuli were presented in lower case. Each letter was made up of dots from a 5 by 7 matrix. A black theater gel covered the screen so that the stimuli appeared clear and sharp. The CRT was adjusted to a comfortable brightness level for each subject. The luminance was occasionally reduced during the experiment because of pupillary constrictions that led to track losses.

The computer kept a complete record of the duration, sequence, and location of each fixation. This allowed for the determination of (a) the first fixation duration on the target, (b) the calculation of initial reading time per word and per letter, and (c) the calculation of total viewing time per word and per letter.

Procedure

Subjects were tested individually. When the subject arrived for the experiment, a bite bar was prepared that later served to reduce head movements during the experiment. Each subject received detailed instructions about the experimental equipment. A calibration of the eye tracking system began each session. The reader was instructed to fixate a visual target that was presented on the left hand side of the CRT for one second; the reader's eye position was sampled during the final 500 msec interval of target fixation. Subsequently, the target appeared at the right hand side of the screen where the sampling procedure was repeated. After the calibration, the target was replaced with three crosses placed equidistant at the left, center, and right side of the screen. The subject's central point of fixation was marked by a fourth cross that moved in synchrony with the eyes. At this stage, the reader was asked to sequentially fixate the three spatial positions; when the fourth cross superimposed itself over each of the three CRT target positions in succession, the calibration was considered to be successful and the text material could be presented. In those instances in which the reader was not able to superimpose the fourth cross on the target, a recalibration procedure

was executed.

In each session, subjects were required to read 10 different stories (2 practice, 4 distractors, and 4 experimental) in a line-by-line manner. The importance of reading for comprehension and integration of text was emphasized by asking subjects to invent a story title after each story had been read. The presentation of one line of text at a time was intended to minimize the number of track losses, to be able to check the reader's tracking alignment continuously, and to insure that all text constituents, including the first word of the line, were fixated.

Each line of text was read in the following manner: An initial fixation marker at the left hand side of the CRT was displayed. This position coincided with the first letter position of the first word of each line. Text was displayed by the experimenter as soon as the subjects central point of fixation was successfully located on the calibration marker. Each line of text consisted of three to nine words which were arranged so that they formed coherent 'idea units' whenever possible. To display new material, the reader pushed a button which replaced the line of text with the fixation marker at the beginning of the line. This checking-presentation-termination cycle was continued until the whole story had been read. In those

instances in which there was a discrepancy between the fixation marker and the reader's central point of view, a recalibration was performed. Subjects were further informed that a one letter mask would move in synchrony with their eyes on half of the trials. The effect of this mask was to completely obliterate the central character of text during each fixation and to replace it with a completely illuminated 5 by 7 letter matrix. The visual impression of the mask was that it consisted of seven short horizontal lines.

A complete experimental session consisted of two successive parts, each of which lasted between 25 and 40 minutes with a 15 minute break in between. Each part began with the reading of a warm up story, half of which was read without, the remainder with, a central mask. The subject then read two filler and two experimental stories half of which were read with and half of which were read without the central mask. (The whole story was read either with or without a mask). The experimental session was concluded with an free recall test; this had not been announced although it should be noted that subjects were reminded that questions pertaining to the meaning of the passages might be asked after the experiment. Subjects were given their invented story headlines with the instruction to recall as much as possible about each of

the 4 experimental and 4 distractor passages.

Design. A 4 by 4 Latin Square design, in which the sequence of experimental stories was counterbalanced, was replicated three times. Although each subject was exposed to all four experimental stories, the design was arranged so that each individual story was read by a group of six subjects without, and by the remaining subjects with a central mask. Thus, mask per story was treated as a between subjects variable. Predictability and word frequency, on the other hand, occurred within each story and were treated as within subjects variables. The words in the different predictability and frequency groups were matched across stories for sentence location and word class whenever possible. Variations of other factors, such as illumination, duration of the experimental session, and prior knowledge, were assumed not to be systematically related to the data.

Scoring. Total viewing time (TVT), initial reading time (IRT), and first fixation durations (FFD) were calculated. Fixations were counted to indicate the processing of a target word when the central point of fixation was either placed on the word or the blank space to the left or the right of critical words. In the latter case, half of the fixation time that fell in between two words was allocated to the two adjoining

words.

Results

Total viewing time. Mean values for the different experimental conditions were calculated for each reader and subjected to two sets of analyses of variance (ANOVAs). In the first set, TVT per word and per letter were used to evaluate the experimental effects; story (4 levels) and mask (two levels) were between subjects variables while predictability (3 levels) was within subjects in one set of ANOVAs and word frequency (3 levels) measures were used in a second set of analyses. In addition to using subjects as a random variable ($F<1>$) error variance was estimated based on stories as a random factor ($F<2>$). Both error terms were combined to calculate $\text{min}F'$ ratios.

The results revealed that low predictable words required a total viewing time (TVT) of 628 (93) msec (TVT per letter in parentheses) followed by medium and high predictable words with 366 (64) and 344 (56) msec, respectively. This effect was significant for the TVT per word analysis ($F<1>(2,47) = 94.81$; $F<2>(2,47) = 73.39$; $\text{min}F'(2,11) = 41.36$, each $p < .01$) and for the TVT per letter analysis ($F<1>(2,47) = 35.87$; $F<2>(2,47) = 63.33$; $\text{min}F'(1,10) = 17.48$, each $p < .01$). The one letter focal mask increased TVTs from 400 (62) msec to 492 (80) msec (word scores: $F<1>(1,47) = 8.17$, $p < .01$; $F<2>(1,47) = 6.55$, $p < .025$; $\text{min}F'(1,11) = 3.64$, $p < .05$

and letter scores: $F<1>(1,47) = 7.29, p <.01$; $F<2>(1,47) = 6.91, p <.01$; $\text{min}F'(1,10) = 3.54, p <.1$).

The TVT values for low, medium, and high frequency words were 543 (71) msec, 386 (63) msec, and 314 (60) msec, respectively, which yielded a significant effect for word ($F<1>(2,47) = 60.11$; $F<2>(2,47) = 38.88$; $\text{min}F'(2,9) = 23.62$, each $p <.01$) and letter scores ($F<1>(2,47) = 4.47, p <.025$; $F<2>(2,47) = 4.18, p <.025$). Again, a one letter mask increased fixation durations and resulted in an average TVT of 449 (74) msec compared with 380 (56) msec in the no mask trials ($F<1>(1,47) = 8.17, p <.01$; $F<2>(1,47) = 6.55, p <.025$; $\text{min}F'(1,11) = 3.64, p <.1$ for word scores and $F<1>(1,47) = 11.17, p <.01$; $F<2>(1,47) = 11.42, p <.01$; $\text{min}F'(1,10) = 5.64, p <.05$ for letters).

The relationship between predictability and masking effects and word frequency and masking effects is depicted in Figure 1. Interestingly, the mask had increasingly detrimental effects as predictability decreased ($F<1>(2,47) = 4.52, p <.025$; $F<2>(2,47) = 5.56, p <.01$ for words and $F<1>(2,47) = 4.28$; $F<2>(2,47) = 4.02$, both $p <.025$ to the letter data). However, there was no indication that words differing in frequency interacted with the focal mask ($F<1> < 1$ and $F<2> < 1$).

To assess the interplay of lexical access and word

Figure 1

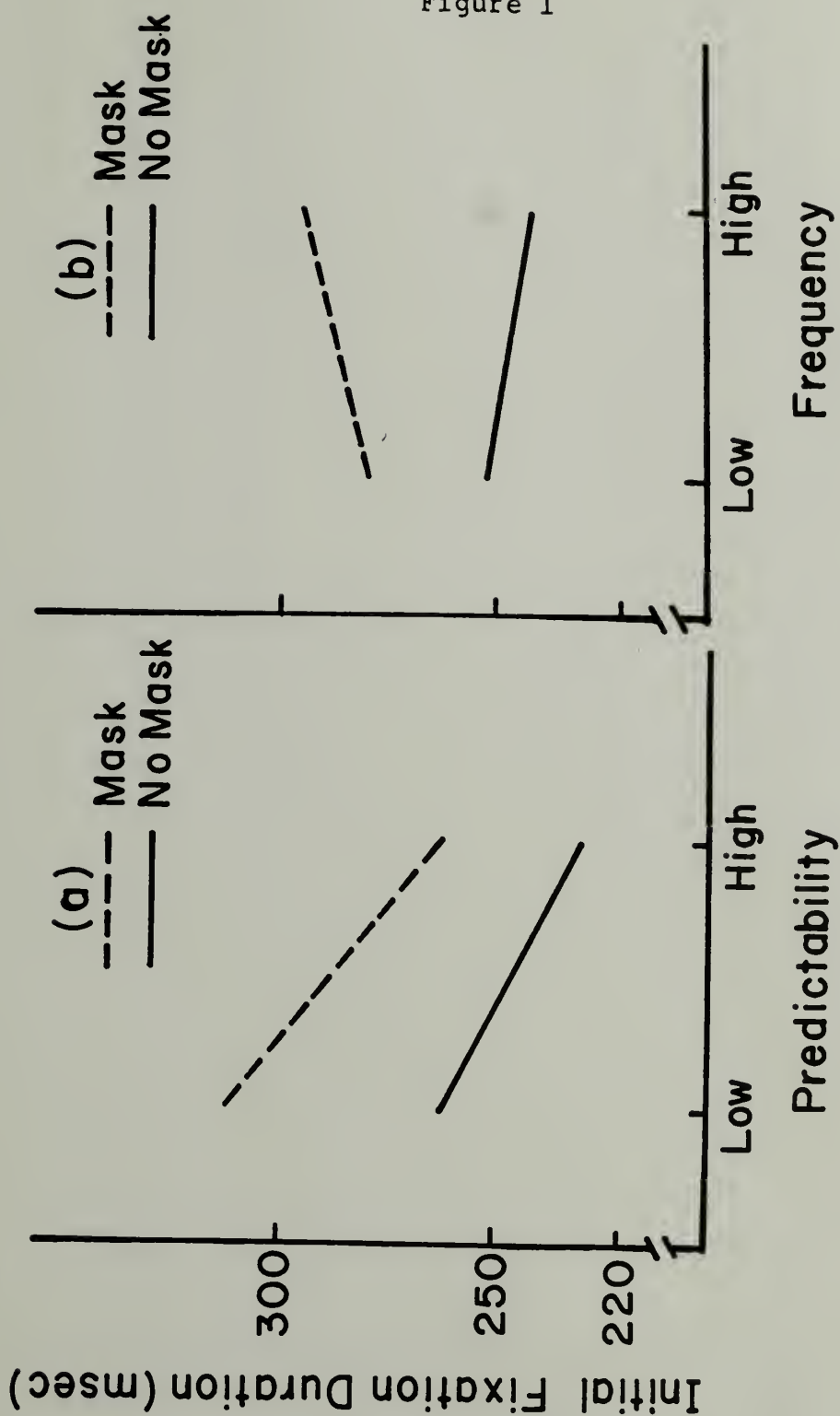


Figure 1 shows the TVT per letter of words differing in frequency and predictability

interpretation orthogonally, a new pooling of the data was performed in which high- and low predictable items were selected separately from a pool of high and low frequency words. In this evaluation, the means per cell were based on four data points per subject. Since the prior analyses revealed virtually identical results for the fixation duration per word and per letter, the analysis was performed only on the fixation durations per word. (Although there may have been some discrepancies between word and letter per word scores. Word frequency effects were more pronounced when word scores were obtained). The results are shown in Figure 2. Again, the TVTs were longer when a low predictable word was fixated than when the reader encountered a high predictable word ($F_{(1,47)} = 99.27$; $F_{(2,47)} = 98.76$; $\text{min}F'(1,10) = 49.50$, all effects $p < .01$) and TVT was longer on highly frequent than on low frequent words ($F_{(1,47)} = 44.43$; $F_{(2,47)} = 47.73$; $\text{min}F'(1,10) = 22.77$, all effects $p < .01$). As in the previous analyses, TVT was longer in the presence of the mask ($F_{(1,47)} = 10.2$, $p < .01$; $F_{(2,47)} = 6.59$, $p < .01$, $\text{min}F'(1,10) = 3.97$, $p < .1$). There was also an interaction between word frequency and predictability. Low frequency words were more affected by predictability, 681 msec low predictability versus 361 high predictability, than high frequency words, 478

Figure 2

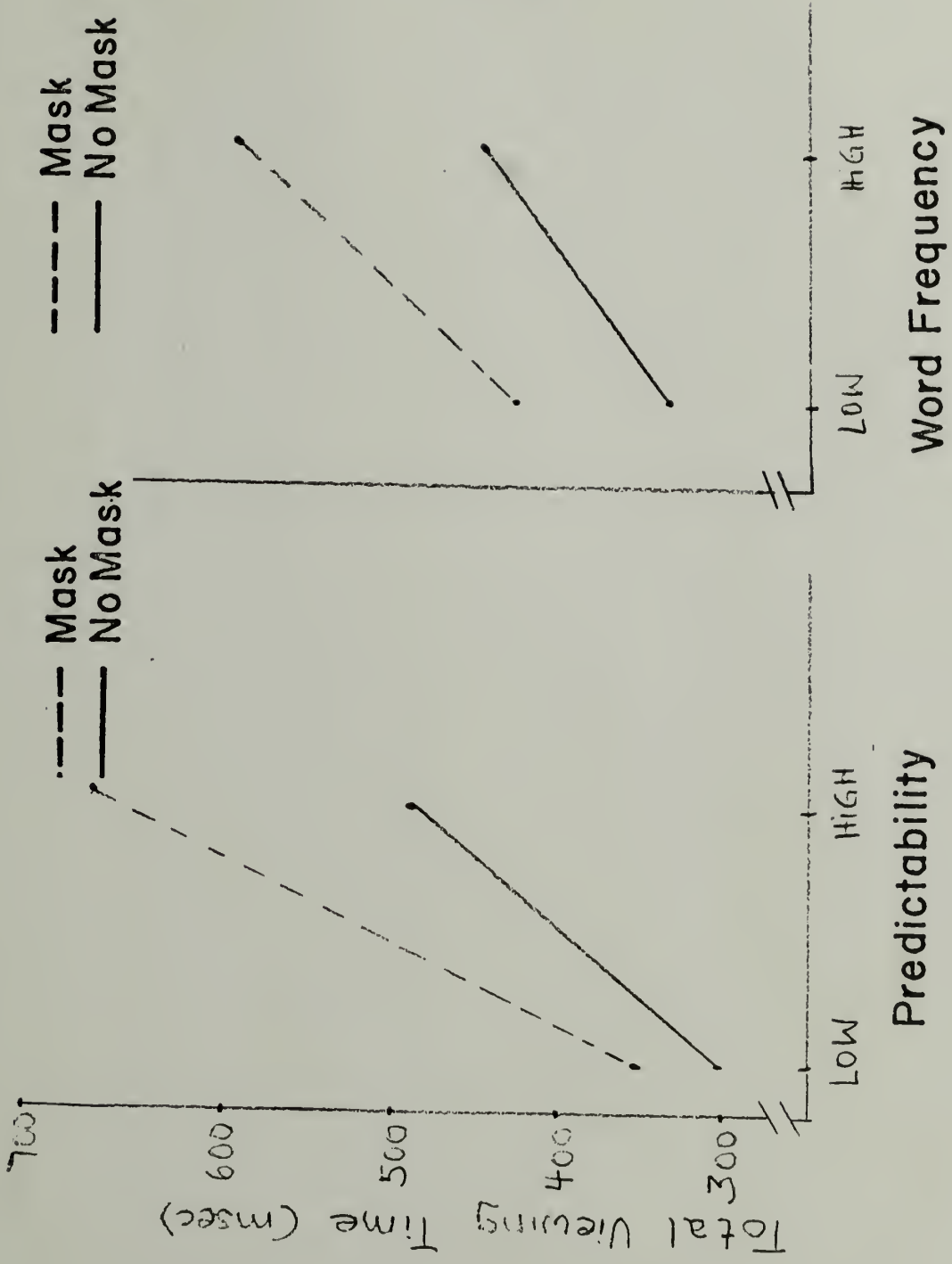


Figure 2 shows the TVTs of words differing in frequency and predictability

msec low predictability and 288 msec high predictability ($F_{<1>}(1,47) = 12.97$; $F_{<2>}(1,47) = 13.43$, both $p < .01$; $\text{min}F'(1,10) = 6.59$, $p < .05$). Again, the interaction of word frequency with the one letter mask revealed no statistically significant trend ($F_{<1>}(1,47) = 1.87$ and $F_{<2>}(1,47) = 1.97$, both $p > .20$) while the predictability and mask interaction was replicated ($F_{<1>} = 6.08$; $F_{<2>}(1,47) = 6.05$, both $p < .025$; $\text{min}F'(1,10) = 3.02$, $p < .1$).

Initial reading time. Initial reading time (IRT) was evaluated separately. This analysis was performed to assess the predictability effects upon the first reading of the critical item, excluding interword regressions to the critical word (this measure roughly corresponds to Just and Carpenter's gaze durations). The data are contained in Figure 3. A 2 (mask) x 4 (story) x 2 (predictability) x 2 (word frequency) ANOVA was performed on the IRT scores. Surprisingly, there was only a marginal effect for the observed increase in IRT in the masking condition ($F_{<1>} = 4.39$, $p < .05$ and $F_{<2>}(1,47) = 2.30$, $p < .1$). Again, the main effects of word frequency and predictability were reliable ($F_{<1>}(1,47) = 33.58$; $F_{<2>}(1,47) = 31.03$; $\text{min}F'(1,10) = 16.12$ and $F_{<1>}(1,47) = 107.28$; $F_{<2>}(1,47) = 94.15$; $\text{min}F'(1,10) = 50.14$, respectively, all effects $p < .01$). As in the TVT analyses, word frequency did not

Figure 3

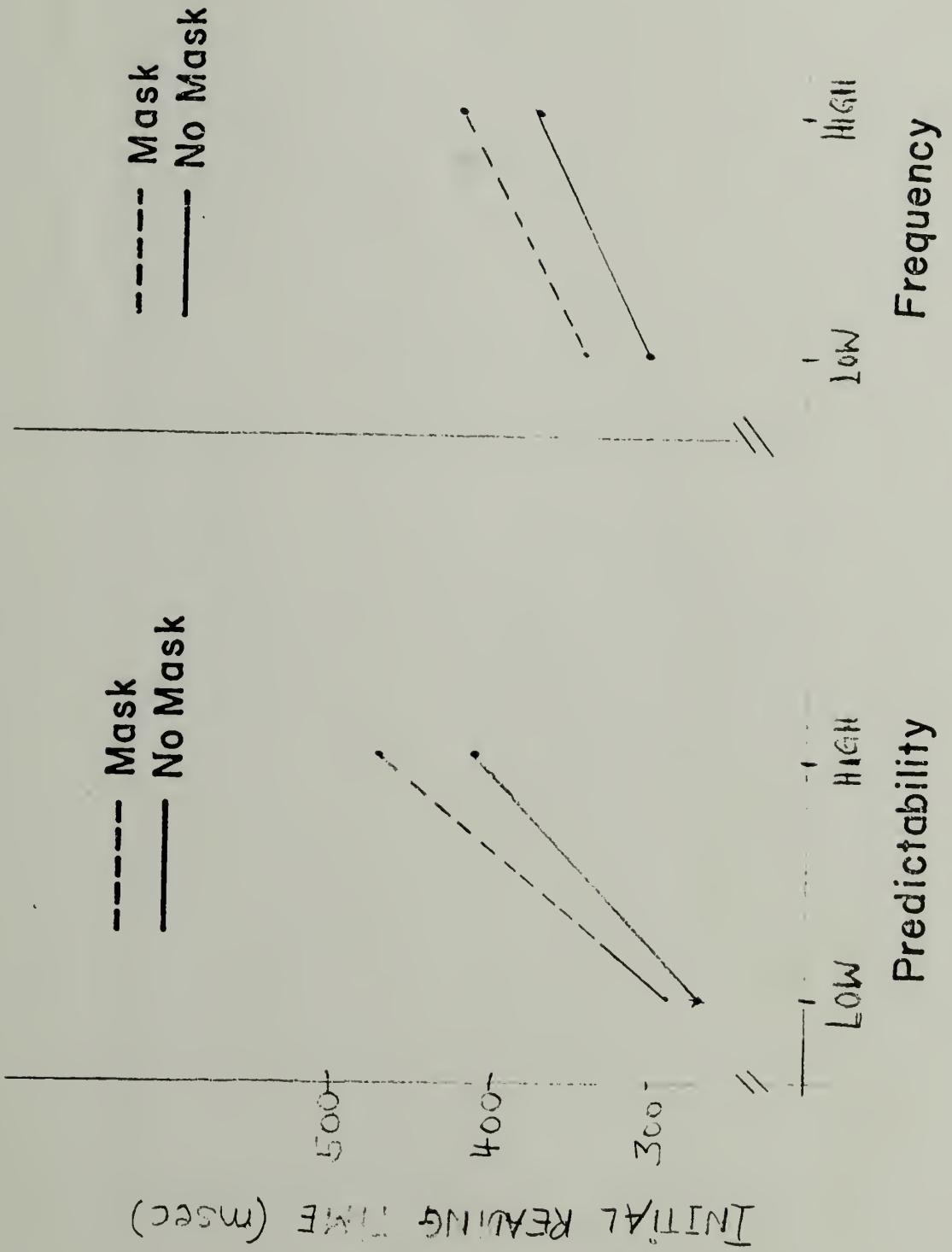


Figure 3 shows the IRTs of target words differing in frequency and predictability

interact with the one letter mask: $F_{(1,47)} < 1$ and $F_{(2,47)} < 1$. However, in contrast to the TVT scores, the interaction between predictability and mask did not reach significance ($F_{(1,47)} = 2.02$ and $F_{(2,47)} = 1.78$).

First fixation duration. Lastly, the effect of word frequency upon the first fixation duration was determined. The data are shown in Figure 4. Mean values of first fixation durations (FFDs) were compared in a 2 (mask) x 4 (story) x 2 (word frequency) x 2 (predictability) ANOVA. FFD increased in the presence of the mask ($F_{(1,47)} = 17.94$; $F_{(2,47)} = 15.40$, both $p < .01$ and $\text{min}F'(1,10) = 8.28$, $p < .05$) and were longer for low predictable than for highly predictable words ($F_{(1,47)} = 36.30$; $F_{(2,47)} = 28.37$; $\text{min}F(1,10) = 16.00$, all effects $p < .01$). The effect of word frequency did not reach significance ($F_{(1,47)} < 1$ and $F_{(2,47)} < 1$). Again, frequency and predictability interacted ($F_{(1,47)} = 6.08$; $F_{(2,47)} = 6.37$, both $p < .025$; $\text{min}F'(1,10) = 3.12$, $p < .1$). There was also a trend for the mask to interact with word frequency ($F_{(1,47)} = 3.38$; $F_{(2,47)} = 3.51$, both $p < .1$) while this trend was not found for the mask by predictability interaction ($F_{(1,47)} = 1.19$ and $F_{(2,47)} = 1.51$, both $p > .2$). This trend towards a word frequency by mask interaction was due to an

Figure 4

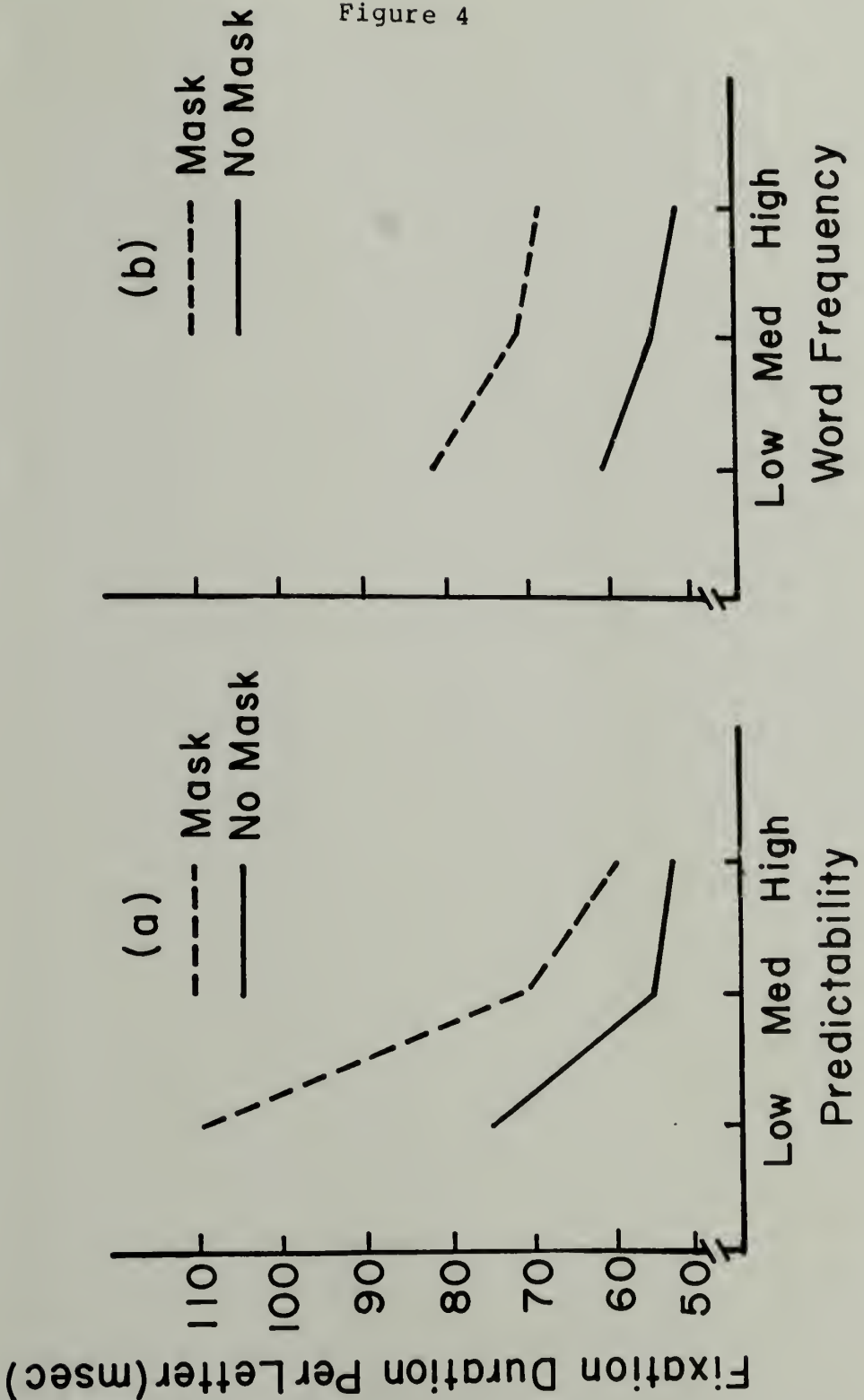


Figure 4 shows the FFDs of target words differing in frequency and predictability

unexpected increase in fixation durations for high frequent words over low frequent words in the masking condition.

Recall performance. To test whether readers were acquiring the gist of the short stories, an evaluation of the free recall protocols was performed by two independent raters. Seventy five percent of the recall protocols were rated as containing gist, indicating that readers were indeed comprehending the short passages. The interrater reliability in the scoring was $r = .80$. Nevertheless, there was a high degree of variability among subjects and stories. Errors in the ordering of events, deletions, and misinterpretations were common.

DISCUSSION

The major questions motivating the experiment were concerned with readers' on line processing routines during lexical access and context dependent word interpretation. Lexical access operations were assumed to be affected by the frequency of individual words while word interpretation was assumed to be closely related to the predictability of individual items. The results showed that different measures of on-line processing, namely first fixation durations, initial reading times, and total viewing times (FFDs, IRTs and TVTs, respectively) were sensitive to both stages of processing. Decreases in word frequency led to increases in viewing time, presumably because lexical look-up consumed more time for low frequency words. Similarly, as the predictability of critical words decreased, the fixation time spent on the item increased so that it appears that readers' on line word interpretation was less readily performed when less predictable words were encountered.

These results suggest that both linguistic manipulations tapped cognitive processing performance during the reading of individual words of text. They are in close agreement with the results of Just and Carpenter (1980) who reported variations in gaze durations due to variations at the lexical and

contextual level of processing. The results also agree with the results of Ehrlich and Rayner (1981) and Friedman (1979) who found longer first fixation durations for low predictable items than for high predictable equivalents (Ehrlich and Rayner's results were obtained in a reading study while Friedman's data were obtained in a picture perception experiment). This pattern of results reveals that variations both at the level of lexical access and word interpretation are responded to with fine tuned adjustments of viewing time, a process that occurred immediately during the first encounter with the item.

However, the increase in processing time with decreases in word frequency and predictability is consistent with both a global cognitive processor that increases processing time as lexical access and word interpretation become more difficult, and with the notion of two autonomous cognitive subroutines. To distinguish between these two possibilities, the effects of the focal mask were explored. It was hypothesized that the mask would exert corresponding effects upon word frequency and predictability if corresponding processing operations are associated with lexical access and word interpretation. On the other hand, the mask was expected to affect both stages differentially if different routines were expected at

each stage.

The results supported the latter view: The central one letter mask combined additively with with word frequency but interacted with predictability when TVT measures were obtained.

This differential effect of the mask upon the two processing stages might simply be due to increases in masking effects as fixation time of individual words is increased. For example, low predictable words were found to require considerably longer total viewing times than low frequency words. Thus, it might be argued that it was the longer reading time required to comprehend the low predictable words, but not the differential processing routines, that yielded the mask and predictability interaction and additive effects of mask and word frequency.

Two findings strongly argue against this view. First, the mask was found to be considerably more interfering with the reading of high frequency words than with the reading of high predictable words, although both required equivalent amounts of total viewing time in the no mask trials. Second, a post hoc analysis was performed which yielded the interaction regardless of the overall masking effects. Two groups of readers were formed, each consisting of four subjects. One group consisted of those readers who

showed the weakest masking effects (the mask increased TVTs by an average of ten per cent), and a second group of readers consisted of those who were strongly affected by the central mask (the mask increased TVTs by an average of 60 percent). Interestingly, both groups had equivalent TVTs in the no mask reading condition. An inspection of the data of both groups showed the same qualitative pattern. The mask combined additively with word frequency and interacted with predictability.

A different pattern of masking effects was obtained when the initial reading times were analyzed. That is, the focal mask combined additively with both word frequency and predictability (although there was some slight trend towards a mask by predictability interaction). Furthermore, the two factors word frequency and predictability, which interacted when TVTs were analyzed, showed additive effects in the IRT analysis. At face value, TVTs and IRTs seem to be inconsistent with each other. However, the inconsistency may be resolved when the differences in the two dependent measures are taken into account. TVT measures included regressive fixation time, a measure that has been closely associated with text comprehension and error recovery (eg. Carpenter & Daneman, 1981). IRT measures excluded these reading

times and may have been more sensitive to the initial lexical processing of the item. Thus, IRTs would be expected to be more closely related to lexical access operations while TVTs would be more closely associated with context dependent word interpretation. The interaction of word frequency and predictability, found for the TVTs, can be explained in similar terms. Lexical access operations may have been sharply reduced during the re-reading of words while conceptual processes were emphasized. During the initial reading, on the other hand, both stages may have consumed independent amounts of processing time.

Finally, it should be pointed out that the data are consistent with the view that different attentional processing routines are executed at each stage. Since the mask was found to slow reading it can be assumed that the mask made reading more difficult and demanded some of the reader's processing resources. Assuming that these resources are limited (Kahneman, 1973), it can be predicted that an attention demanding mask will interact with other attention demanding processes, since both are competing for limited processing resources. On the other hand, the mask is expected to combine additively with processing routines that can be executed automatically. In this case, no competition for processing resources will take place. Applying

this interpretation, the present results suggest automatic lexical look-up routines and an effort consuming word interpretation stage. This view is consistent with Yates' (1978) data interpretation described earlier; however, it is not consistent with Becker (1976) who found effort consuming lexical access operations and with Britton (Britton, Holdredge, Curry, & Westbrook, 1979; Britton, Westbrook & Holdredge, 1978) who showed that the reading of easy text required less processing capacity than more difficult text.

C H A P T E R V

EXPERIMENT 2

The results of Experiment 1 supported an on line model of text comprehension that included at least two cognitive stages of text processing. One stage, called lexical access in which individual word properties like word frequency are evaluated, and a second stage in which individual words are interpreted, presumably within the context of prior prose and conceptual information. The experiment showed that a central one letter mask that moved in synchrony with the readers' eyes affected the two stages differentially. Based on this it was concluded that lexical access and word interpretation can constitute two autonomous subroutines in reading.

However, the experiment raises a series of questions. Predictability ratings in Experiment 1 may have been based both on context and on individual word characteristics. For example, novel words, though highly consistent with prior text, may have received low predictability ratings. Thus, predictability and word frequency may have, in part, required corresponding processing structures during the reading of text. For example, there were slight, though consistent trends towards an interaction of word

frequency by mask both for the IRTs and TVTs and it remains possible that a more powerful manipulation of one of the variables might yield a reliable interaction. Furthermore, Experiment 1 showed a significant interaction of mask by predictability for the TVTs only. This may be due to the fact that particularly difficult text had been used that favored readers' regressions to recover from erroneous interpretation (eg. reeling might have been initially interpreted as reading). Thus it remains possible that easier text, which does not elicit an excess of regressions will show only additive effects of the the mask and predictability.

Experiment 2 explored these possibilities to corroborate and extend the findings of Experiment 1. Mask size was increased from one character space to three character spaces. Again, individual word characteristics and context dependent word properties were used to manipulate the two hypothesized stages of word processing. Unlike Experiment 1, logical criteria were used to assess individual word characteristics and context dependent word properties. More specifically, criteria elaborated by Kirparsky and Kirparsky (1971) were used to manipulate individual word characteristics. Two classes of verbs were used, each class implying a different set of lexical

presuppositions; namely factive verbs that imply the truth of the following complement and nonfactive verbs that do not impose a corresponding constraint. Although these verbs were not expected to differ in lexical access time, it was assumed that the lexically more complex factive verbs would require longer lexical processing operations once the lexicon had been entered (analogous to the increases in phoneme detection time after hearing a lexically ambiguous word). A more complex lexical representation was expected to result in longer fixation times spent on the item.

Experiment 2 used a manipulation of context dependent word interpretation that rested on logical grounds. 'Correct' and 'incorrect' words were used; 'correct' words preceded factive and nonfactive verbs and were consistent with prior context, 'incorrect' words, on the other hand, followed factive and nonfactive verbs and were inconsistent with prior context by means of stating a false fact. It was assumed that 'correct' concepts were easier to integrate into the conceptual text representation than 'incorrect' words. Thus, shorter fixation times are predicted for 'correct' than for 'incorrect' words.

Factivity and correctness were expected to affect fixation time of critical words so that factive and incorrect words were expected to receive longer

fixation times (TVT, IRT, and FFD) than nonfactive and correct complements. Given the nature of the restriction carried by factive verbs, we might also expect a factivity by correctness interaction, with false complements taking longer after factive verbs. Under masking conditions, however, the two linguistic factors were expected to yield different results. The mask was predicted to combine additively with factivity but to interact with correctness. Mask size was increased from one to three character spaces to increase the possibility of finding a factivity by mask interaction. In contrast to Experiment 1, conventional (text) was used, to minimize the chances of regressive eye movements and to increase the chances of additive effects of context dependent word properties (correctness) and mask effects.

METHOD

Subjects. Subjects were 16 paid volunteers recruited from the University of Massachusetts subject pool. None of the subjects required corrective lenses for reading.

Apparatus and Procedure. The same apparatus and procedure as in Experiment 1 was employed with the exception that readers were not required to invent a story title after each text section. Instead, to ensure reading for meaning, each paragraph was followed by a question that either asked for a specific detail of the story (eg., Is speeding legal in the US?) or which probed the reader's text interpretation (eg. Does the world have a flat surface -- see Table 2).

Material. Sixteen paragraphs were constructed, each of which encompassed a short episode that was easy to understand. Individual word characteristics were varied so that correct words were validly primed by prior context. In the example presented in Table 2, the correct word limit was preceded by the concepts speed, driver, and exceed. In contrast to this, incorrect words could not be anticipated by prior context. The incorrect words were either preceded by a factive or nonfactive verb. Another control, in which the factive and nonfactive verb was followed by a

Table 2

A ball put on a well-made table
will only move if the table top is tilted.<a>
this proves <1> / suggests <2>
that the earth is flat.

Does the world have a flat surface?

The highway plice look out
for drivers that exceed the speed limit.<a>
when we were stopped, after having gone
more than 80 mph, we were surprised<1>/ hopeful<2>
that speeders get a cash reward.

is speeding legal in the us?

<1> factive

<2> nonfactive

<a> correct expression

 incorrect expression

Table 2 shows two passages of trest that were used in
Experiment 2.

correct complement was not realizable. The small set of factive/nonfactive verbs did not allow for the construction of a sufficiently large set of additional stories without paying the price of repeating factive and nonfactive verbs. To compensate for this, and to avoid the reader's anticipation of some incorrect items, a set of 26 filler stories, each without any false information, was randomly interspersed between the experimental passages.

Design. Two lists were constructed, each containing 16 experimental and 26 filler stories. The two lists were identical with the exception that the position held by a factive verb in one list was filled by a nonfactive verb in the other list; thus, list was used as a between subjects variable. A three letter central mask was presented during the reading of half of the stories in a blocked manner. The sequence of mask and no mask blocks was balanced across subjects. The sequence of factive and nonfactive verbs was varied randomly within each list. Each experimental story also contained one correct and one false concept. Correct concepts always preceded incorrect ones. Factive and nonfactive verbs as well as correct and false expressions were matched for sentence position and closely matched for word length. False complements and correct expressions were identical across lists.

Other factors, such as line length and story length, varied randomly.

This allowed the application of two sets of ANOVAs to analyze the data. One set, that was to evaluate the processing of correct and incorrect words, consisted of a 2 (list) by 2 (mask: zero vs 3 letters) by 2 (correct vs incorrect item) by 2 (factive vs nonfactive verb context) factorial design. The second set of ANOVAs that served to analyze the factivity effects consisted of a 2 (list) by 2 (mask:0 vs 3 letters) by 2 (factive vs nonfactive verb) factorial design. List served as a between subjects variable, all other factors were manipulated within subjects. Estimates of error variability were based on subjects only ($F < 1$).

Scoring. As in Experiment 1 total viewing time (TVT), initial reading time (IRT), and first fixation duration (FFD) were calculated. A critical word was considered to be fixated when the readers' focal point fell on one of its component letters or the blank space immediately preceding it. In those instances in which a central three letter mask was applied, the critical word was counted as being fixated whenever the critical word could be read and no material of the preceding word was to the right of the mask. The fact that all but two of these critical items held terminal line positions generally eliminated the necessity of

determining right cut-off points. For those items that were followed by text, the item was considered to be beyond the range of evaluation as soon as the first letter of its right hand neighbor was perceptible.

RESULTS

Total viewing time. The TVTs are shown in Table 3, averaged across subjects and stimuli. Correct items received an average TVT of 495 msec while incorrect words were fixated for 633 msec ($F(1,14) = 18.0, p < .01$). The mask increased TVTs from 425 msec to 712 msec ($F(1,14) = 30.1, p < .01$) and also interacted with correctness ($F(1,14) = 14.4, p < .01$), ie. correct words were less interfered with than incorrect concepts. There was also a reliable effect of the context provided by factive and nonfactive verbs. Correct and incorrect expressions embedded in a story with a factive verb consumed longer TVTs than correct and incorrect expressions embedded in a story containing a nonfactive verb (523 msec versus 605 msec, respectively); this difference was statistically reliable ($F(1,14) = 11.1, p < .01$). In addition, the factivity context interacted with mask application ($F(1,14) = 13.2, p < .01$), indicating that the mask interfered more with the reading of correct and incorrect concepts that were presented within a story containing a factive verb than with the reading of concepts that were presented within a nonfactive verb context. Although superficially compelling, part of the latter two results remain impossible to explain. Concepts preceding factive verbs were identical both in

Table 3

	no mask				mask			
	correct		incorrect		correct		incorrect	
	NF	F	NF	F	NF	F	NF	F
FFD	273	267	265	270	271	298	271	297
IRT	360	370	370	432	393	618	565	726
TVT	392	394	434	443	496	697	769	885

NF = nonfactive context

F = factive context

Table 3 shows different mean fixation times obtained for the different context dependent target words.

form and linguistic context to the concepts preceding nonfactive verbs; nevertheless, they were found to consume longer TVTs in the mask condition (496 msec vs 697 msec). Since single line presentations were used, the result cannot be explained by the excessive use of regressive eye movements to correct items preceding factive verbs when the mask was presented.

To explore whether this unexpected difference was due to some exceptionally long fixations on a few items, median values were computed for those subjects that showed longer TVTs when correct expressions preceded a factive verb than when these items preceded a nonfactive verb. Though this analysis showed the same data pattern as did the mean values, the effect was slightly reversed when sentence reading time (SRT) was computed. Sentences preceding factive verbs were found to consume slightly shorter SRTs when a factive verb was to occur later in the story than when a nonfactive verb was to follow (2072 msec vs 2101 msec). Thus sentences that preceded factive and nonfactive verbs received equivalent SRTs although subjects may have distributed fixation locations differentially, so that the correct words preceding the factive verb may have received, by chance, longer TVTs than correct complements preceding nonfactive verbs. This opens the possibility that median SRTs also showed equivalent

reading times for the phrases following factive and nonfactive verbs. However, sentences containing incorrect complements continued to require longer SRTs when they followed a factive verb than when they followed a nonfactive verb (2735 msec vs 2459 msec, $t_{(15)} = 4.95$, $p < .01$).

To control for the effects of individual word characteristics, the effects of factivity were explored. The results showed that factive verbs consumed an average total fixation time of 621 msec which was not significantly different from the 644 msec required to encode the nonfactive verbs ($F < 1$). There was a reliable masking effect with 450 msec in the no mask trials and 816 msec in the masking condition ($F(1,14) = 27.1$, $p < .01$). In addition, there was a significant list effect ($F(1,14) = 5.4$, $p < .05$).

Initial reading time. Initial reading time results are also shown in Table 3. The overall pattern of the data closely corresponds to the TVT results. Again, the mask increased viewing time of the correct and incorrect concepts (383 msec and 575 msec, respectively); ($F(1,14) = 15.5$, $p < .01$). Also, correct items received shorter duration initial reading times than incorrect words (435 msec and 523 msec, respectively; ($F(1,14) = 6.3$, $p < .025$). Interestingly, and unlike the IRT findings of Experiment 1, the mask

interacted with correctness ($F(1,14) = 4.6, p < .05$), indicating that incorrect words were more interfered with than correct words when the central mask was applied. Similar to the TVT analysis, there was a reliable effect of factivity context and an interaction of this factor with mask application. Again, both correct and incorrect expressions required longer fixation times (IRTs) when read in a factive context than when read in a nonfactive verb context and the mask interfered to a stronger degree with correct and incorrect concepts in the factive than in the nonfactive context. (The unexpected finding of effects of factivity upon the correct items has been explored during the presentation of the TVT data).

The IRT data obtained for the factive and nonfactive verbs also replicated the TVT data. The mask increased IRTs reliably from 384 msec to 659 msec ($F(1,14) = 32.4, p < .01$) and nonfactive verbs consumed slightly longer IRTs than factive verbs (541 msec versus 502 msec); this difference was not reliable ($F(1,14) = 1.15, p > .30$).

First fixation duration. There was some tendency for first fixation durations to increase when the central mask was applied. The no mask condition resulted in an average FFD of 269 msec while the mask showed an average FFD of 289 msec; however, this effect

only approached significance ($F(1,14) = 2.72, p < .12$). None of the remaining effects reached significance. In particular, correct and incorrect concepts received virtually identical FFDs (277 msec and 281 msec, respectively).

FFDs of factive and nonfactive verbs followed a similar pattern. Again, the mask increased FFDs from 249 msec to 293 msec ($F(1,14) = 7.5, p < .025$) while there was no reliable difference between factive and nonfactive verbs (262 msec and 281 msec, respectively).

DISCUSSION

The results of Experiment 2 replicated those of Experiment 1 in demonstrating first, that correct, contextually constrained expressions received shorter encoding operations than incorrect expressions, presumably because the latter are more difficult to integrate into the reader's conceptual story representation. Second, correct words required less additional processing time than incorrect expressions when a three letter central mask was applied. This mask by correctness interaction further shows that the mask interaction effects must include effects due to word integration (not encoding or lexical access) since items are correct and incorrect only by virtue of being consistent or inconsistent with asserted propositions. In addition, the results revealed that the critical correctness by mask interaction was not restricted to the TVT analysis but also occurred when IRTs were evaluated. This suggests that readers relied less on regressive eye movements to comprehend the story when the text was relatively easy to follow; in this case, readers may have tried to integrate and interpret individual words during the initial reading. However, it should be noted that correct and incorrect words generally occupied the last word position on an

individual line of text. This, of course, prevents readers from regressing back to the critical item after additional information has been sampled (unlike in Experiment 1). Instead regressions to the critical item only occurred when readers regressed to prior text section and then back to the critical word.

Unlike the results obtained in Experiment 1, there was no reliable effect of contextual constraints (correctness) upon the duration of the first fixation. Again these differences may be due to the overall differences in text difficulty. The contextual constraints may have been less effective in Experiment 2 than in Experiment 1 so that reliable differences only occurred when more global measures were obtained.

Unfortunately, Experiment 2 did not reveal lexical effects corresponding to those of Experiment 1. Factive verbs, which were assumed to require a more complex lexical representation than nonfactive verbs, did not receive longer encoding operations than the nonfactive expressions; thus, the additive effects of mask application were theoretically unconvincing. Comparable results have been reported recently. Cutler (1982) found no reliable difference in phoneme monitoring latencies when target phonemes followed factive or nonfactive expressions. (This result had not been available at the time of conducting the

experiment). Thus, once the reader entered the lexicon, factive and nonfactive verbs may have elicited equivalent lexical processing operations. And, integrating these verbs with context, both factive and nonfactive verbs may have been encoded with a truth anticipating component. This is suggested by the cooperative principle (cf. Clark & Clark, 1977) which states that listeners/readers expect the speaker/writer to tell the truth, presumably regardless of the factivity status of the preceding verb. That is, readers still expected a cash fine, instead of a cash reward after they had read that the driver was stopped for speeding, regardless of the preceding verb type.

However, a look at the fixation time of incorrect complements that followed a factive or nonfactive verb indicates that factivity affected the processing of following complements. Incorrect words following a factive verb consumed longer fixation times than incorrect concepts following a nonfactive verb which supports the view of different cognitive representations of factive and nonfactive verbs. Unfortunately, there was also an unexpected increase of fixation time of correct concepts that preceded factive verbs over identical concepts that preceded nonfactive verbs. Additional analyses suggest that this effect may have been due to a differential distributions of

phrase reading time. An analysis of median sentence reading time indicated that readers spent equivalent amounts of sentence reading time when correct items preceded factive and nonfactive verbs. SRTs of phrases that contained incorrect complements, on the other hand, consistently showed longer processing times for phrases following factive verbs than for identical phrases following nonfactive verbs.

C H A P T E R V I

GENERAL DISCUSSION

The goal of the present investigation was to study readers' on line processing performance during the reading of prose. Two stages of cognitive processing, namely lexical access and context dependent word interpretation, were assumed to constitute distinct processing stages during readers' text comprehension. Both stages have repeatedly been shown to affect response times in priming and phoneme monitoring studies. In particular, low frequency words, which presumably require more extensive lexical look-up operations, have been found to yield longer response latencies than high frequency words. Comparably, low contextual constraints, that may increase readers' interpretative efforts, have been shown to yield longer processing times than high contextual constraints. The present experiments confirm these findings. High frequency and contextually constrained words (ie. high predictable and correctly primed words) were found to require shorter duration visual inspections during reading than low frequency words and low predictable and incorrect items. In addition, the present results show that these processing operations are executed on line, i.e. while individual words are being fixated.

Most crucially, the data support the view that the two cognitive processing routines are performed autonomously. A central pattern mask, which moved in synchrony with the readers' eyes combined additively with word frequency but interacted with context dependent linguistic manipulations.

Overall, these results are in close agreement with the two stage model outlined in the introduction, according to which lexical processing operations require qualitatively different processing operations than conceptual, interpretative operations. In its outlined form, the model contended that lexical processing, including lexical entry and lexical meaning activation, and conceptual word interpretation occurred on line during the initial reading of individual words.

Though this extreme model cannot be rejected, the data only demand a more limited processing model. In particular, lexical entry and lexical meaning activation may, or may not, constitute a unitary stage of lexical processing that preceded context dependent word interpretation. Although there was evidence that lexical entry, as measured in word frequency, was effectively biasing fixation time, there was little support for the assumption that more complex lexical representations (factive versus nonfactive verbs) required different amounts of on line processing time.

As a further specification, the data of Experiment 1 may indicate that readers may delay the interpretation of difficult words until additional text has been read; in this case, word interpretation may tend to take place during readers' regressions to these items. Concepts that are relatively easy to interpret, on the other hand, seem to be evaluated during the initial encounter. These assumptions account for the central mask by predictability and correctness interaction when TVT measures were obtained and for the reliability of this interaction for IRTs, only when relatively easy text was to be comprehended.

In spite of these constraints, it may be assumed that the data essentially support the general class of word processing models which assume at least two independent cognitive stages of word processing. Two of these models, Stanovich and West's two-process theory and Becker's verification model will be more closely scrutinized.

Based on the Posner and Snyder (1975) work, Stanovich and West (1979; 1981) suggested that word processing is accomplished by two qualitatively distinct processing systems. The first is a spreading activation process which takes place when stimulus information activates a memory location, as it may occur during lexical look-up. This activation will also

automatically spread to nearby semantically related memory locations. A second, slow acting, effort consuming attention mechanism becomes activated after some amount of time. Thus, as the temporal processing of a word is lengthened, the effortful mechanism is more likely to be implicated in the performance. For example, when target identification is delayed via the application of some type of visual degradation, the reader is likely to switch from a quick automatic mode of processing to an effortful mode. According to this view, it is the temporal processing requirements, not the particular stage of processing, that effectively determines the quality of the processing operations. This implies that equivalent processing time requirements in the no mask condition of the present experiments should yield equivalent masking effects (since equivalent processing strategies are pursued). This position has been shown to be unable to accommodate the results: Highly predictable and high frequency words that consumed equivalent processing times in the no mask condition were differentially affected by the application of the central mask.

At face value, Becker's (1976; 1979; 1980; Becker & Killion, 1977) verification model seems to be best suited to fit the results. The model postulates an initial stage of visual feature extraction; this

feature extraction consumes time and is a function of stimulus quality. Based on the initial set of extracted features, readers generate a set of potential word candidates that will be sequentially tested against the most recently encoded visual features (more specifically, the top candidate is used to predict additionally sampled visual features). Candidate testing does not occur randomly. Rather, Becker assumes that the more frequent a particular word, the higher the probability that it will be checked first. Thus, individual word characteristics, such as word frequency, affect word processing. In addition, Becker's model contends that context will bias the selection of a particular set of word candidates. A small number of potential word candidates will be activated when contextual constraints are high; a larger number of possibilities is held available under low contextual constraints. This candidate generation is not affected by individual word characteristics.

Aside from this formal similarity of Becker's model and the present conception, the verification model is well suited to accommodate a large section of the present results. In particular, the model predicts additive masking effects upon word frequency and interactive effects upon predictability provided that masking delayed the initial stage of visual feature

sampling. (The model assumes that the temporal bottleneck of word processing is located at the stage of visual feature extraction. Visual degradation will slow these processes and increasingly interfere with feature extraction the more readers rely on visual feature extraction. That is, the mask will have more detrimental effects for low predictable words than for highly predictable words since more word candidates will have to be checked against the incoming visual features in the former case. Word frequency, on the other hand combines additively with the mask because it does not affect the set of potential word candidates.)

Though compelling, this framework only partially satisfies the data. First, the mask seems to exert different effects than stimulus degradation. Pattern masks have been shown to affect more cognitive processing operations while brightness manipulations affect peripheral, low level operations (Turvey, 1974), so that the central mask may have interfered with cognitive processes while visual degradation slowed visual feature extraction. Other differences between brightness manipulations and the mask have been spelled out in the introduction. Furthermore, Becker's model only accomodates the TVT data of Experiment 1. Different processing strategies may have been employed

during the initial reading of target words and readers may use different encoding strategies when easy text is read than when difficult text is to be comprehended. Recent modifications of the verification model (Eisenberg & Becker, 1982) have been geared in this direction. According to this view, readers may engage in two different contextually induced verification strategies. One, called the prediction strategy, is used when target words are highly likely. Here only a few alternatives are generated. Second, when subjects' expectations are relatively undefined the number of word candidates is increased; this is referred to as the expectancy strategy. However, even if it is assumed that readers tend to regress when the expectancy strategy is used (ie. under low contextual constraints), the model would still fail to explain the crucial role of regressions in Experiment 1; ie. why were the masking effects most detrimental during the re-reading of individual words?

Thus it appears that the present data are difficult to accommodate within two stage processing models that originate from single word experiments. These models are essentially lexical models of word processing that cannot accommodate conceptual evaluations. This conceptual processing has been claimed to occur after the individual word has been retrieved from the lexicon

and is reminiscent of the Haviland and Clark "Given-New Effect" (1974).

Subsequently, some implications of these results upon models of reading and eye movement measurements will be considered and some future directions will be sketched.

An Evaluation of Eye Movements. Although the present results validate eye movement records as a dependent measure for the exploration of reading and, presumably, memory processes, there are considerable difficulties still associated with this approach. The role of monitoring accuracy and parafoveal word perception will be considered and some discussion will be given to different units of analysis.

Monitoring accuracy: Conventional eye movement measurements allow for some degree of variability with respect to the determination of the exact fixation position. For example, Just and Carpenter and Kliegel et al. used a recording system that was only able to discover eye movements of more than 2 to 3 character spaces. The range of insensitivity may not be critical when long words are being fixated and when readers direct their focal position towards the center of the word (a strategy generally followed by readers, O'Regan, 1980; Rayner, 1979). However, relating fixations to text becomes more difficult with this system when the reading of short or particularly long words is to be considered. For short words, preferred viewing position is close to word boundaries and long words frequently receive multiple fixations, one at the beginning and one fixation towards the end (Rayner, 1979). In this case, the system may not be able to

differentiate between the fixation at the end of one word and the fixation at the beginning of another. Another accuracy limitation refers to the sampling rate of the tracking system. For example, Just and Carpenter's and the Kliegl et al. system sampled eye position every 16.7 msec which implies that the eye may have been in motion up to this amount of time before the system registered the termination of the fixation. The present system avoided these sources of variance. A highly accurate eye monitoring system was used with a resolution of less than one character space and a sampling rate of 1000 Hz.

Parafoveal word perception: A precondition for using fixation time per word as a dependent variable is the validity of the assumption that only the fixated word is being processed (Carpenter's eye-mind assumption). However, McConkie and Rayner (1975) and Rayner (1975) showed that readers gained effective visual information from the parafovea in addition to the fixated word and this finding has been corroborated in a host of additional studies (eg. Rayner & Bertera, 1979; Rayner et al. 1981). More recent investigations also revealed that it is the processing of the initial letters of the parafoveal word which accounts for the facilitation of parafoveal

word perception in reading (eg. Rayner, McConkie, & Zola, 1980). Thus, rather than starting from scratch during each fixation, the reader has preprocessed the fixated word during the previous fixation (and also engages in some additional processing of the right hand parafoveal word while a particular target word is fixated). These preprocessing effects may be constant across fixations and not systematically affect target fixation durations. However, the fact that some words are skipped while others receive multiple fixations argues against a strictly constant effect of parafoveal processing. This raises the question of how fixations placed upon a target word are to be converted into "pure" target processing time.

Somewhat related to this issue is the general assumption that all possible psycholinguistic processing requirement of the fixated word are met during the fixation of the target. The present literature (eg. Rayner & Pollatsek, 1981; Ehrlich and Rayner, 1983) does not strictly rule out the possibility that the processing of a word is occasionally extended across successive fixations that may cover different words.

The "true" unit of text analysis: At present, different measures of fixation time are being used.

Just and Carpenter used gaze durations while Rayner (1978; Ehrlich & Rayner, 1981) preferred average fixation time and first fixation durations placed on targets. Kliegl et al. argued in favor of the latter measure since it can be determined according to an outside criterion that sums the time at a location until there is a "substantial" shift in location of the fixation. If analyzed with respect to words, a second dependent measure can be obtained, i.e. the number of fixations falling on a word. Gaze durations do not allow this distinction between the duration and number of fixations. In particular, Kliegl et al. pointed out that the more global gaze duration may attribute perceptually determined variability to cognitive processing. For example, a re-fixation of a word and the associated increase in gaze durations may not be due to increased cognitive processing requirements but may simply reflect the reader's need to have an accurate visual representation of the re-fixated word section. However, the Kliegl et al. position seems relatively extreme. First, gaze durations can be determined according to an outside criterion since it is defined as the viewing time spent within particular, defined letter boundaries (these boundaries are independent of fixation time). Second, perceptual variables may be controlled by using different units of

analysis. For example the Kliegl et al. argument loses weight when gaze durations per letter are calculated (and individual words are equated for word length effects). The present study used a variety of different on line measurements including first fixation durations and gaze durations (which corresponds to IRTs) and also used different units of analysis, namely whole words and letters per word. The results, particularly of Experiment 1, show that the evaluation of different sets of eye movement data, rather than of one "true" set of data, may be advantageous.

CHAPTER VI I

FUTURE DIRECTIONS

As already indicated, and independent of the theoretical considerations of the last sections, the present investigation left one theoretically compelling question unanswered and raised some new ones. In particular, the relationship between the different aspects of lexical processing and context dependent word interpretation requires more experimental attention. It still remains to be seen whether all lexical processing (including lexical meaning activation) contributes to the former or, alternatively, whether it is only the lexical look-up process per se. To further explore this issue, one might use ambiguous and unambiguous target words such as mole and book in the following sentences:

There was a big mole on the ground.

There was a big book on the ground.

If lexical processes beyond lexical look-up contribute to this first stage, we would expect additive effects of ambiguity and a central mask. By contrast, ambiguities which depend on the integration of words into a sentence or conceptual structure would be expected to interact with a central mask.

The present data also raise questions concerning the reader's attentional processing. In particular, the

data suggest automatic lexical entry and effortful text interpretation. A secondary task, for example auditory probe presentation, may be used to test the hypothesis. Auditory probes could be presented while subjects are fixating individual words that differ in frequency and predictability. Provided that lexical processing occurs automatically, it is expected that probe detection latency remains relatively unaffected by variations in word frequency; on the other hand, if word interpretation consumes different amounts of effort, probe detection latency is expected to increase as the predictability (or correctness) of fixated target words decreases.

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