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VISUAL SELECTIVITY IN READING:
A STUDY OF THE RELATIONSHIP BETWEEN
EYE MOVEMENTS AND LINGUISTIC STRUCTURE

A Dissertation Presented

By

ANTHONY S. COMUNALE

Submitted to the Graduate School of the
University of Massachusetts
in partial fulfillment of the requirements
for the degree of

DOCTOR OF EDUCATION

May, 1973

Major Subject: Research in Education and Psychology

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May, 1973

To my wife and parents

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

THE PROBLEM

Purpose of the Study

Since Dodge (1907) first called attention to the fact that whenever the visual mechanism functions the activity is always accompanied by eye movements and fixations, a number of researchers have studied eye movements and their relationship to reading and linguistic variables.

The main premise of the present study is that eye movements are an integral part of the reading process and that studying eye movements and their relationship to linguistic variables will add to the understanding of the reading process.

Wanat (1970) has conducted a number of experiments designed to explore the relationship between selected measures of eye movements and linguistic structure. Wanat used six sentence types which differed with respect to their linguistic structure. His major conclusion was that eye movements were related to changes in sentence types.

The present study is an attempt to extend the findings of the Wanat study. The question of central concern is the relationship of selective visual behavior to the reading text; i.e., are there differences in the amount of visual "attention" mature readers allocate to linguistically-defined areas in an active sentence?

Review of the Literature

Selective Visual Scanning

In normal adult reading, the eye makes about three to five stops (called fixations) per second, remaining relatively still for an average of 300 milliseconds at a time (Neisser, 1967). Of course, the eyes are not absolutely still during each fixation, but the effect of the small nystagmoid fluctuations is irrelevant for this discussion.

Evidence suggests that while the reader is visually scanning the text certain information in the text may not be "attended" to. That is, the deletion or addition of certain aspects of the text may make no difference in the reader's behavior. Pillsbury (1897) reports that adult readers can read materials without reporting errors such as function words which may be repeated (e.g., "The, the") or deleted. One of the strongest indications that the normal adult reader attends to less than the complete textual information is the phenomenon of proofreaders' errors. Experienced readers can read material and not notice errors such as letter substitutions, transpositions, omissions or additions.

Woodworth and Schlossberg (1954) report that 90 percent of the time spent in looking at a visual display is devoted to fixating parts of the display, leaving ten percent of the time for moving the eye from one fixation to the next. Given that one-thousandth of the visual field is in "hard focus" during any fixation and since fixational pauses are roughly one-fourth of a second, a case for visual selectivity can be made. If one-thousandth of the display area is in focus during a fixation, then the indication is that subjects can "process relevant information" from visual displays without putting into "hard focus" every detail of the visual display.

Hochberg (1970) has described the reading process as follows:

> "A practiced reader samples a display of the text, rather than looking at each letter. He has learned to respond effectively to the few features seen with clear foveal vision by expecting an entire word or even a phrase. He needs to fixate only the parts of the array farther along the page that will enable him to formulate new guesses as well as to check his current guesses. His expectations of what he will find are based on the syntax and the meaning of what he has just read, and they must also be based on the blurred view provided by peripheral vision."

An experiment by Kolers (1970) supports the contention that the reader does not attend to the complete information available. In that experiment Kolers presented text as a temporal succession of letters appearing at a fixed point in the visual field. He found that it took 250 milliseconds per letter for subjects to report the text. Even when consideration was given to visual masking (Levin & Williams, 1970), the reading rate was sufficiently slow and the subject, by adopting a letter by letter strategy, could not approach the speed of reading of a reader who was not forced to adopt this letter by letter strategy. Since average college students read about 300 words per minute and subjects in the Kolers experiment were reading at about 42 words per minute, Kolers concluded that skilled reading cannot be a process of successive identification of each and every letter.

Additional studies indicate that words are identified by less than the identification of every letter. Marchbanks and Levin (1965), in an experiment designed to test what cues beginning readers look for, found that children preferred to use first letters, final letters, middle letters and word shape in that order of preference as cues to word identification.

Further evidence suggesting that the reader does not attend to all letters in a word comes from experiments which force the subject to deal separately with every word in a list. In an experiment by Pierce and Karlin (1957) in which subjects were asked to read (aloud) a list of familiar three-syllable words, they attained rates of about three per second, or 350 milliseconds per word. With shorter words, somewhat higher speeds were achieved. Even quicker recognition appeared in studies by Neisser and Beller (1965) and Neisser and Stoper (1965). In these studies the subjects looked through a list of words, three to six letters in length, in search of one which denoted an animal or (in another condition) a proper first name. This task, it would seem, required the subject to establish enough of the meaning of each word to determine whether it belonged to the target class. Yet with trained subjects, scanning rates came to exceed five words per second, or less than 200 milliseconds per word. According to Neisser (1967, p. 108), scanning times in the above experiment are incompatible with the hypothesis that the subject establishes several letters, one after the other, and then infers the identity of the word from them alone. Neisser (1967, p. 109) cites data which indicate that even naming a single letter alone must take over 100 milliseconds.

The above studies tend to suggest that: (1) mature readers do not attend to all the letters in a word, and (2) mature readers do not attend to all the words in a sentence. If this is the case, then one could argue that the reader is selectively processing the text. This conclusion leads to an obvious question: what parts of the sentence are important in terms of processing information from the text?

Sensitivity to Linguistic and Grammatical Structure

Sensitivity to linguistic structure has been shown by a number of experiments which require subjects to identify the location of an auditory "click." In these experiments subjects receive an auditory presentation of sentences; during the presentation auditory clicks are produced so that they occur at varying locations within the sentence. After the sentence has been presented, subjects are asked to report where the clicks occurred. Bever, Lackner and Kirk report (Bever, 1970) that subjects locate clicks subjectively between a verb and its complement object significantly more often for "noun-phrase" verbs (e.g., "They desired * the General to fight") than for "verb-phrase" verbs (e.g., "They defied * the General to fight"). Fodor and Bever; Garrett, Bever and Fodor; and Bever, Fodor and Garrett have studied the perception of non-speech interruptions (clicks) in sentences with two clauses (Bever, 1970). The basic finding is that subjects report the location of a single click in a sentence as having occurred not at its presented location but more toward the area between the clauses. For example, in the sentence "Because it rained yesterday the picnic will be cancelled," Fodor and Bever found that a click objectively located in "yesterday" or in "the" was most often reported as having occurred between these two words.

According to Bever (1970), "Several experiments have shown that this systematic effect of the syntactic segmentation is not due to any actual pauses or cues in the pronunciation of the sentence." Bever reports two studies (Garrett, Bever and Fodor; Abrams, Bever and Garrett) which manipulated acoustic sequence; still the results showed that the clause structure assigned each word sequence "attracted" the subjective location of the clicks.

The importance of grammatical structure has been shown by Gladney and Kralee (1967) in their demonstration that tampering with the verb interferes most with reading the sentence. In this study, errors were introduced into sentences in a systematic way in order to study their effect on a subject's performance. More specifically, the experimental variables included two basic syntactic structures: (1) three alternative positions in sentences for the introduction of an error in place of the subject noun, the main verb or the object noun; and (2) two parts of speech, adjective and adverb, for the introduction of an error. The sentences were presented with and without knowledge of the presence or absence of an error in the presentation. It was found that errors in place of the main verb were more disruptive than were errors in either the subject or object positions. The relative importance of the sentence verb has also been shown by Fodor, Garrett and Bever's (1968) experiment which indicated that the nature of the complement structure of the verb affects ease of reading.

In another experiment by Kolers, sensitivity to grammar was shown by having students read material which had been geometrically transformed (i.e., reversed right to left, mirror image, etc.). The errors that subjects made were analyzed for part of speech substitution (i.e., the number of times that a substitution was the same part of speech as the printed word). The results showed that about three-fourths of the errors of nouns, verbs and prepositions were of this nature. Ordinarily, contemporary linguists have analyzed words by the functional role they play in a sentence (e.g., object of the verb, subject, etc.) rather than by their taxonomic categories (e.g., noun, adjective, etc.); however, Kolers' experiment shows that the reader is not reading "just groups of letters," but is sensitive to their grammatical category. In an experiment designed to test the reader's sensitivity to grammatical structure, Kolers (Levin & Williams, 1970, p. 105) found that in some cases the reader was more sensitive to the grammatical relations of what he was reading than to the printed words themselves.

Eye-Voice Span

The technique of measuring the eye-voice span (EVS) and its use in studying the role of grammatical structure in reading has been studied by a number of researchers. The EVS is defined as the distance, usually measured in words, that the eye is ahead of the voice when reading aloud. There are two general procedures in studying the EVS: eye movements are recorded while the subject is reading aloud, or the text is removed while the subject is reading and the subject is asked to report as much of the text as he can beyond the point at which oral reading was interrupted.

Levin and Turner (1968) studied the EVS and its relationship to the number of words contained in phrases in an active sentence. Using two, three and four-word phrases, they found that the EVS is rather sensitive to phrase size and tends to expand and contract in order to better fit phrase boundaries.

Using the EVS technique, Schlesinger (1969) found that people tend to read to the end of units, chains or phrases which are both syntactic and semantic wholes.

Levin and Kaplan (1968), using the EVS as a dependent variable, found that readers had a longer EVS in the area following the verb in passive sentences than in active sentences.

Other studies by Wanat and Levin (1968), Lawsen (1961), and Morton (1964) found that distance between the eye and the voice tended to increase as the amount of contextual constraint increased. That is, the EVS was longer when the reader expected a particular category of word because of a particular kind of structural feature (e.g., an underlying agent in a passive sentence type).

Thus, all the studies reviewed support the notion that the reader is sensitive to grammatical structure. The next question to be examined considers the relationship between grammatical structure and one component of reading: eye movements.

Grammatical Structure and Eye Movements

One of the earliest studies of eye movements and the nature of the reading material was conducted by Judd and Buswell (1962). In that study differences in recorded eye movements with differences in reading task were reported; however, in their experimental procedure they did not systematically vary grammatical structure of the text.

More recently, Mehler, Bever and Carey (1967) studied the effect of specific linguistic variables on eye movements. By manipulating phrase structure, they formulated the general eye fixation rule that the reader fixates on the first half of each immediate constituent. In other words, the linguistically-defined phrase structure determines the unit of fixation. Mehler, Bever and Carey's experiment was an important step in relating eye movements to linguistic variables; however, as Wanat (1970) points out, there are some major difficulties with their study:

> "First, they discarded approximately half of their data. One of their criteria for discarding records of eye fixations was the presence of many fixation points on the record. A case in which the reader had to fixate many points suggests the presence of factors in the sentence which made it difficult to process visually, yet, this served as a basis for discarding the record. Second, their technique only took into account whether or not an area was fixated. They did not differentiate between forward fixations and regressions. Thus, there was no way to determine if a particular area was regressed to, or whether a regressive movement originated at a particular area. Their procedures also failed to take into account the duration of a fixation. It is impossible to determine from their data if some areas took more time to process than others. Finally, Mehler, Bever and Carey used sentences which were ambiguous. Since relatively few sentences encountered in natural reading situations are ambiguous, it is possible that this characteristic of their test materials may limit the generalizability of their findings. In summary, although the Mehler, Bever and Carey study attempts to examine the effect of specific linguistic variables, limitations in the type of eye fixation measure used, the type of records retained for analysis, and the nature of the reading materials, all raise questions about the validity of the study."

Morton (1964) examined the relationship between contextual constraint and the number of both forward (left to right) and backward (right to left) eye movements. Morton's results showed that the greater the contextual constraint (i.e., the more predictable the sentence) the smaller the number of both forward and backward eye movements. Since Morton used statistical approximations to normal English, there is a major limitation in generalizing to normal reading.

Wanat's Study

The most ambitious attempt to relate eye movements to the structure of the reading material has recently been completed by Wanat (1970). Wanat's study was an attempt to build upon past experiments which in some cases studied eye movements without regard to varying linguistic structure and in other cases manipulated linguistic structure without regard to measuring eye movement.

Wanat's independent variables were: (1) area of sentence, (2) structure of sentence, and (3) mode of reading (oral or silent). Five dependent measures of eye movements were used in the Wanat study: (1) number of forward fixations, (2) time spent on forward fixations, (3) number of regressions from areas, (4) number of regressive fixations to areas, and (5) time spend on regressive fixations.

The following is a summary of the specific section of Wanat's study which is of concern to the present work:

> "In the present study, the eye movements of twelve mature readers were studied. Each subject was tested separately. He read forty sentences at each of two test sessions. Half of the test items were read silently, and half were read aloud. The equipment used to photograph the reader's eye fixation patterning was a wide-angle reflection eye camera (Mackworth, 1968). This camera provides a motion picture record of the test display as it is reflected on the subject's eye. When the motion picture film is developed and examined, the outline of the pupil is seen to encircle the area of the stimulus being fixated by the reader. On the film, different areas of the visual display are shown to be successively encircled by the pupil as the reader successively fixates different areas along the line of print. The center of the pupil marks the position of the display being fixated (Mackworth, 1968). For each frame of the motion picture film, the procedure was to locate the center of the pupil, and then to determine what part of the sentence was being fixated.

> "The first question dealt with in analyzing the results of this study concerned differences in the amount of visual attention allocated to individual areas in the sentence: Was there significant variability in the amount of visual attention allotted to the different areas of the sentence? Analysis of variance of the scores for each of the five measures of eye fixation patterning showed significant variability in the scores for individual areas. Thus, the hypothesis that the reader selectively allocates his visual attention to different areas of the sentence was supported."

Wanat's hypothesis relative to selective visual attention to different areas of the sentence was tested across left-embedded and right-embedded sentences, active and passive sentences, and agent-included and agent-deleted passive sentences. Wanat's conclusion was that in every sentence type cited above there were differences in visual attention which were related to linguistic and grammatical structure.

Wanat's study was an attempt at relating eye movements to linguistic structure. There are, however, some considerations with which his study did not deal. For example, subjects were not pretested as to their reading ability. Secondly, consideration should be given to the measurement of two of the dependent variables used in the Wanat study: time spent on (1) forward fixations and (2) backward fixations. Both of these dependent measures were arrived at by multiplying the number of picture frames for each area of the sentence by 200 milliseconds. Since the film speed was five frames per second, the result was assumed to be an estimate of total time spent on each area of the sentence. Because Wanat was using a camera shutter speed of 100 milliseconds, computing durations of fixations in this fashion would yield an approximation to actual total fixation duration; however, no real time recordings of average fixation time were made. Moreover, it has been shown that fixation durations are variable anywhere from 180 to 350 milliseconds (Morton, 1964). The implication of this is that some areas of the sentences under consideration might have more fixations than other areas, but actual average duration of fixations may have been less. Insofar as accuracy of the quantification of average duration fixation is important, Wanat's findings suffer.

Although the major thrust of the Wanat study was directed at analyzing the relationship between eye movement and linguistic structure, sentences were analyzed by measuring eye movements and their relationship to equally spaced areas of sentences rather than an analysis by linguistically-defined areas. Therefore, Wanat's analysis was valid when considering one sentence type as compared to another with regard to number of fixations; however, it does not answer the question of the relationship of eye movements to linguistically-defined structures within the sentence. The present study is concerned with the relationship of eye movements to linguistically-defined areas within the sentence.

Statement of the Problem

The issue is whether place of and duration of eye fixations favor particular linguistically-defined words or word phrases. Until the Wanat study and the Mehler, Bever and Carey (1967) study, no serious attempt at analysis of the relationship between structural linguistic variables and eye movements had been undertaken. Tinker's earlier (1958) review of eye movement research in reading reported no studies which were concerned with variables in linguistic structure. With regard to linguistic variables and eye movements, much the same was true for Bower's (1964) research review.

In the review of the literature it has been argued that there are serious problems with the Mehler, Bever and Carey study and that the Wanat study did not test for the relationship between average visual fixation durations and linguistically-defined areas within a sentence, so that the question of within-sentence "visual selectivity" remains unanswered. The purpose of the present study is to measure eye fixation placement and durations within a particular sentence type. Therefore, the present study proposes to systematically vary the constituent parts of an active sentence (i.e., subject, verb and object) in order to adequately control for testing visual eye fixation placement and durations within a particular sentence type (i.e., an active sentence with a transitive verb: see Table I). These experimental sentences have the physical and relative positions of the subject, verb, and object of the verb moved by the insertion of a prepositional phrase, so that if eye fixation placement or durations favor either subject, verb, or object of the verb it will not be due to the physical arrangement of the subject, verb, and object of the verb in the experimental sentences.

The Major Hypotheses

Major Hypothesis I

There will be a greater frequency of forward and backward[1] eye

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[1] Forward eye fixations refer to an eye stop after a left-to-right eye movement, and backward eye fixations refer to an eye stop after a right-to-left eye movement.

TABLE I

Experimental sentences and associated prepositional phrases, which can occur at one of four places with regard to the kernel sentence: in the beginning, between the subject and verb, between the verb and object, or at the end of the kernel sentence. The prepositional phrase has been inserted in the kernel sentences to change physical and relative position of the subject, verb, and object of the verb.

	Experimental Kernel Sentences	Prepositional Phrase	Kernel Sentence Description
1.	The present governor entered the fall primaries.	At the capital	Subject and object have modifiers
2.	The dark room scared the small child.	In the house	
3.	The hockey player disliked the bad call.	On the ice	
4.	The angry mob hanged the young murderer.	In the town	
5.	The lazy student failed the hard exam.	In the school	
6.	The medical doctor cured the patient.	In the office	Subject has modifier
7.	The new pants fit the man.	In the store	
8.	The bored student sharpened the pencil.	In the room	
9.	The wide road spoiled the park.	In the city	
10.	The mysterious box contained the bomb.	In the building	
11.	The poet wrote the ancient verse.	In the book	Object has modifier
12.	The rain brought the needed relief.	In the country	
13.	The policeman stopped the young speeder.	In the car	
14.	The farmer painted the old barn.	In the fall	
15.	The cloud filled the dark sky.	In the winter	
16.	The problem distressed the boy.	In the class	No modifier for subject or object
17.	The rain ended the game.	At the field	
18.	The bulb shocked the man.	In the room	
19.	The sun dried the mud.	In the summer	
20.	The airplane destroyed the mood.	In the show	

fixations for that linguistically-defined area of a selected experimental sentence which contains the verb, as compared to either the area of the subject or the area of the object of the verb. This hypothesis is a continuation of Wanat's (1970) study of "frequency of fixations."

Major Hypothesis II

There will be differences in the average durations of forward and backward eye fixations for the linguistically-defined areas of the selected experimental sentences. This hypothesis is suggested by a review of the literature and is an extension of the Wanat (1970) study.

Exploratory Hypothesis

There will be no differences between average eye fixation durations which occur in the three position-defined selected experimental sentences.

Background for exploratory hypothesis. When subjects read, one characteristic of their visual behavior is that backward eye fixations (i.e., regressions) occur at various locations in the reading material. These backward movements can be described by measuring the duration of the two fixations before the eye makes the right-to-left movement, and/or they can be described by recording the duration of the fixation following the right-to-left movement.

Tinker (1958) reports that eye fixation latencies are, on the average, 172 milliseconds. If fixation durations prior to a backward movement approached 172 milliseconds, one might speculate that the subject's decision to make a backward movement occurred before the fixation prior to the backward movement, since the subject would have little time left to input information relative to a decision to regress. Even if the fixation prior to the backward movement was greater than 172 milliseconds but shorter than the fixation duration after the backward movement, one might speculate that the reader started to make the decision to visually regress before the fixation prior to the backward movement. If, however, it is found that fixation duration prior to the backward movement was longer than the fixations after the backward movement, one might speculate that the decision to visually regress occurred during that fixation prior to the backward movement.

Because of the absence of evidence in the literature which attempts to investigate the above issue, a further analysis of the active sentences will be concerned with comparing fixation durations which occur before and after backward movements. Three position-defined kinds of fixations will be analyzed for average time:

1) the second fixation before the backward movement;
2) the first fixation before the backward movement; and
3) the first fixation after the backward movement.

The above position-defined fixations will be selected from all fixations occurring within the experimental sentences, without regard to the particular area in the sentence.

Since there are few empirical data upon which to base a prediction of direction with regard to fixation durations before and after backward movements, the null hypothesis is proposed.

CHAPTER II

METHODS

Subjects

Ten subjects were selected from students and staff at the University of Massachusetts.

Stimuli

Twenty active sentences printed in standard elite type on an IBM typewriter were photographed and presented to the subject by means of a rear screen projection technique. The experimental active sentences were positioned on a screen in front of the subject so that they approximated normal distance and size of reading material (i.e., subtended 25° of visual angle and were fifteen inches from the subject's eyes).

In a study by Clark (1966), students at Johns Hopkins University were asked to generate active sentences. No specific instructions were given to the Johns Hopkins students concerning content of the active sentences; only the form of the sentence was specified. The present study uses the Clark study sentences; the only modification of the sentences is the insertion of the constructed prepositional phrase (see Tables I and II).

Procedure

Subjects were told that the purpose of the study was to examine eye

TABLE II

An experimental sentence showing the four transformations used in the experiment. Subjects received at random only one of the four transformations.

KERNEL SENTENCE: The new pants fit the man.
PREPOSITIONAL PHRASE: In the store

First Transformation: Prepositional phrase inserted at beginning of kernel sentence	In the store the new pants fit the man.
Second Transformation: Prepositional phrase inserted between the subject and verb	The new pants in the store fit the man.
Third Transformation: Prepositional phrase inserted between the verb and object	The new pants fit in the store the man.
Fourth Transformation: Prepositional phrase inserted at end of kernel sentence	The new pants fit the man in the store.

movements in reading and that a record would be made of their eye movements as they read a number of sentences. Subjects were questioned to insure that they had 20-20 corrected vision.

Each subject was tested separately, and each read twenty test sentences during the experimental session. In addition, before the experimental sentences two practice sentences were presented to familiarize the subject with the procedure.

Subjects were selected for reading proficiency by the following: only subjects that scored between 250 and 350 words per minute on the first part of the 1960 Nelson-Denny Reading Test were asked to read (silently) the experimental sentences, which were presented on a screen in front of them.

Each subject was told that he would be shown a series of sentences, one at a time. He was told to "attend" to the "meaning" of the sentences and that after he read the series of test sentences he would be asked to identify some of the words which occurred in the sentences.

At the beginning of the experimental test session all subjects were given the following instructions: "On the screen in front of you, you will see twenty sentences which will be presented one at a time. When I tell you, please read the sentence silently to yourself and then close your eyes." Before each sentence E calibrated the eye track recorder (see description of calibration procedure under "Scoring"). When calibration had been achieved for each experimental sentence, E instructed S to read the sentence to himself and then close his eyes.

After the subject had read all twenty experimental test sentences, he was given a short multiple choice test (see Table III). This test consisted of twenty items, each containing four words. Only one word in each item was also a word which appeared as either the subject, verb or object in the experimental test sentences. The results of a subject were included in the final analysis if that subject scored above chance on the multiple choice test. The multiple choice test was used to gain more confidence that the subject was doing more than just visually scanning the experimental sentences.

Experimental Design

Each subject received all levels of the independent variables. A repeated measures design dealt with comparing average fixation duration and frequency of fixations for each of the three linguistically-defined categories: subject, verb, and object. In addition, the mean fixation durations of forward and backward eye movements to an area were compared. Since there were five dependent measures, the data were analyzed three times, twice for the first two dependent measures and once for the last three dependent measures (see description of dependent measures under "Variables").

The Formal Designs

I. To test Major Hypothesis I (using frequency of fixations as the dependent measure):

A three-factor analysis of variance repeated measures design: 3 x 2 x 4 x 10 (heads of constituent phrases, three levels: subject, verb, object; by direction of fixations, two levels: forward and

TABLE III

Multiple choice test given to each subject after the experimental sentences. One word in each of the twenty items appeared in an experimental sentence presented to the subject.

DIRECTIONS: In each group of four words, circle the one you remember seeing. Circle only one word.

1.	produce	speak	water	entered
2.	people	woman	child	mother
3.	player	morning	sea	together
4.	door	town	dollar	neighbor
5.	exam	success	learn	tell
6.	distance	office	station	hill
7.	husband	wife	read	pants
8.	laugh	stick	sharpened	smoke
9.	love	put	sick	road
10.	group	kiss	bomb	met
11.	wrote	mountain	light	lady
12.	happy	car	hundred	grew
13.	yellow	boat	chair	stopped
14.	grass	barn	king	dress
15.	winter	join	window	knight
16.	admit	head	problem	long
17.	deal	game	build	egg
18.	iron	queen	outside	dried
19.	summer	still	touch	lord
20.	apple	shot	airplane	truth

backward; by four positions of the prepositional phrase insertion; by ten subjects).

II. To test Major Hypothesis II (using average fixation duration as the dependent measure):

An analysis of variance repeated measures design: 3 x 2 x 4 x 10 (heads of constituent phrases, three levels: subject, verb, object; by direction of fixations, two levels: forward and backward; by four positions of the prepositional phrase insertion; by ten subjects).

III. To test the Exploratory Hypothesis (using average fixation duration as the dependent measure):

A one-way analysis of variance repeated measures design: 3 x 10 (backward eye fixation durations, three levels: second fixation duration before the backward movement, fixation duration before the backward movement, and fixation duration after the backward movement; by ten subjects).

Since total time equals mean fixation time multiplied by frequency of fixation, an additional analysis of total time was computed as a data check. Formal Designs I and II were used with total time spent fixating as the dependent measure.

Since every subject did not always look at every area of each sentence, the analysis of mean fixation time was modified to account for the unequal n's. In order to overcome this deficiency, the mean for each area in each sentence type, across the existing data for the five repetitions of each sentence type, was computed and inserted into the missing cell. When the mean sums of squares were being calculated, one degree of freedom was subtracted for every cell that had a "mean" inserted (Fortune, private conversation, 1972).

The recording of eye movements for one sentence intended for presentation to one of the ten subjects was lost because of a projector failure. For that subject, four rather than five repetitions of Sentence Type I appeared on the screen. When the data were analyzed, the four sentences for which eye movements were recorded were weighted to represent five sentences (see Tables V, VI and VII).

Variables

Independent Variables

Linguistic constituents (i.e. subject, verb, object of the verb) within twenty selected active sentences were analyzed by recording eye fixations associated with those constituents. Stated in linguistic terms, the independent variable in the present research is composed of the heads of the constituent phrases within twenty constructed active sentences (see Table I). For example, in the sentence "The boy hit the ball," the subject "boy" is the "head" of the noun phrase "the boy"; the verb "hit" is the "head" of the verb phrase "hit the ball"; and the object "ball" is the "head" of the noun phrase "the ball." Three levels of the independent variable (i.e., head of the constituent phrase) are used: subject, verb, and object of the verb.

Since "head of the constituent phrase" was used as an independent variable, it was necessary to counterbalance for position effect of the subject, verb, and object. Four transformations of the twenty basic sentences were randomly assigned to each subject's sequence of sentences (see Table II) with the restriction that each subject receive an equal number of transformations. The transformations of the twenty basic sentences differed with respect to the placement of a prepositional phrase which had the effect of physically displacing the position of the subject, verb, or object. The twenty basic experimental sentences were taken from a study by Clark (1966) and the construction of the prepositional phrases, using words taken from the Thorndike list of the 500 most frequently-used words in the English language, was done by the experimenter.

Dependent Variables

Five separate measures of eye movements were used. The first two of the five dependent measures were used in testing Major Hypotheses I and II, and the last three measures were used to test the Exploratory Hypothesis.

The dependent variables are:

1) Frequency of both forward and backward eye fixations. For a given linguistically-defined area of the experimental sentences, this is the computation of the number of times the subject fixated that area from the left or the right.

2) Average duration of both forward and backward eye fixations. For a given linguistically-defined area of the sentence, this is the computation of the total length of time that the subject fixated that area divided by the number of times the subject fixated that area.

3) Average duration of fixations which occurred immediately previous to the fixation before a backward movement. For all given areas

of the sentence, this is the computation of the total length of time that the subject fixated that area divided by the number of times the subject fixated that area.

4) Average duration of fixations before a backward movement. For all given areas of the sentence, this is the computation of the total length of time that the subject fixated that area prior to a backward movement divided by the number of times the subject fixated that area.

5) Average duration of fixations after a backward movement. For all given areas of the sentence, this is the computation of the total length of time that the subject fixated that area after a backward movement divided by the number of times the subject fixated that area.

Apparatus

One way to increase the accuracy of photographic measurement of fixation duration would be to run a photographic eye camera at a fast rate. Another way would be to employ a continuous recording device which records all movement on a continuously moving film or graph paper. The present study employs the latter method of recording fixation duration.

The specific equipment used to record the subject's eye movements was the Eye-Trac, a product of Biometrics Company (see Figures 1a, 1b, and 1c). The Eye-Trac (U.S. Patent No. 3,583,794) is an instrument which utilizes electronic and optical techniques to obtain measurements of both the dynamic and static components of eye movements. The photoelectric monitoring technique employed allows the measurements to be

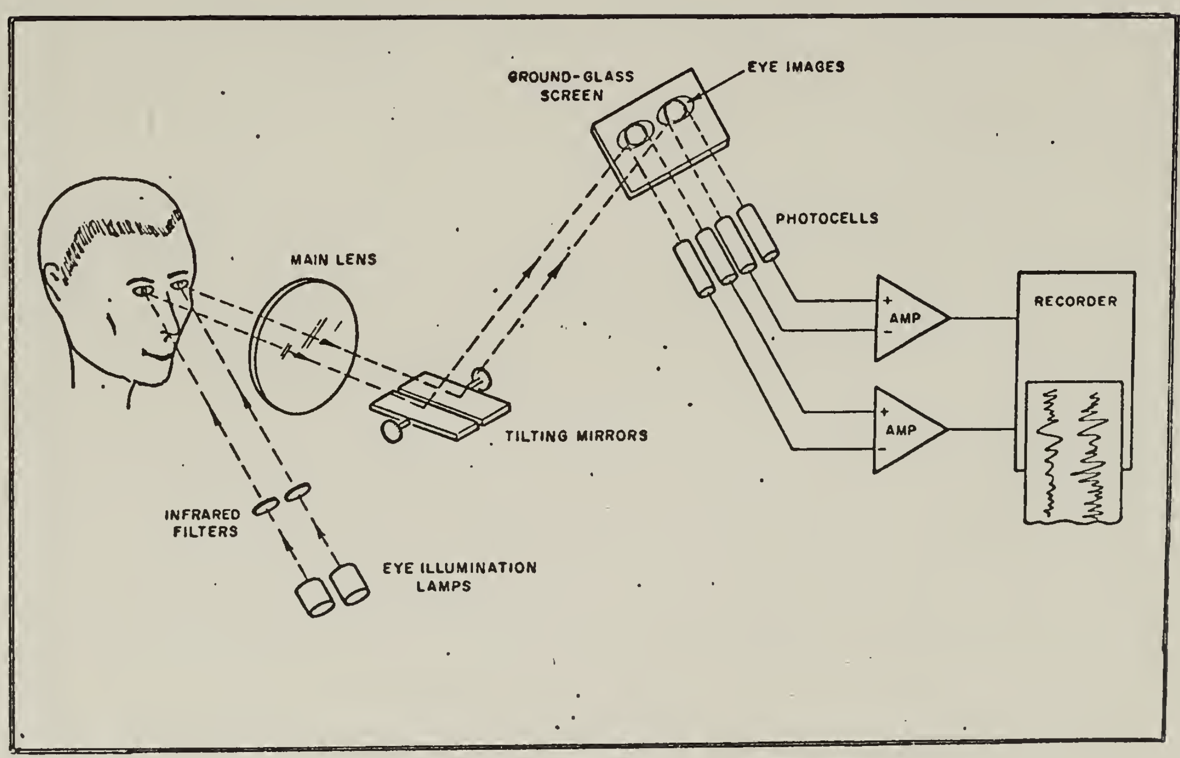


FIGURE 1a

Eye-Trac Functional Diagram

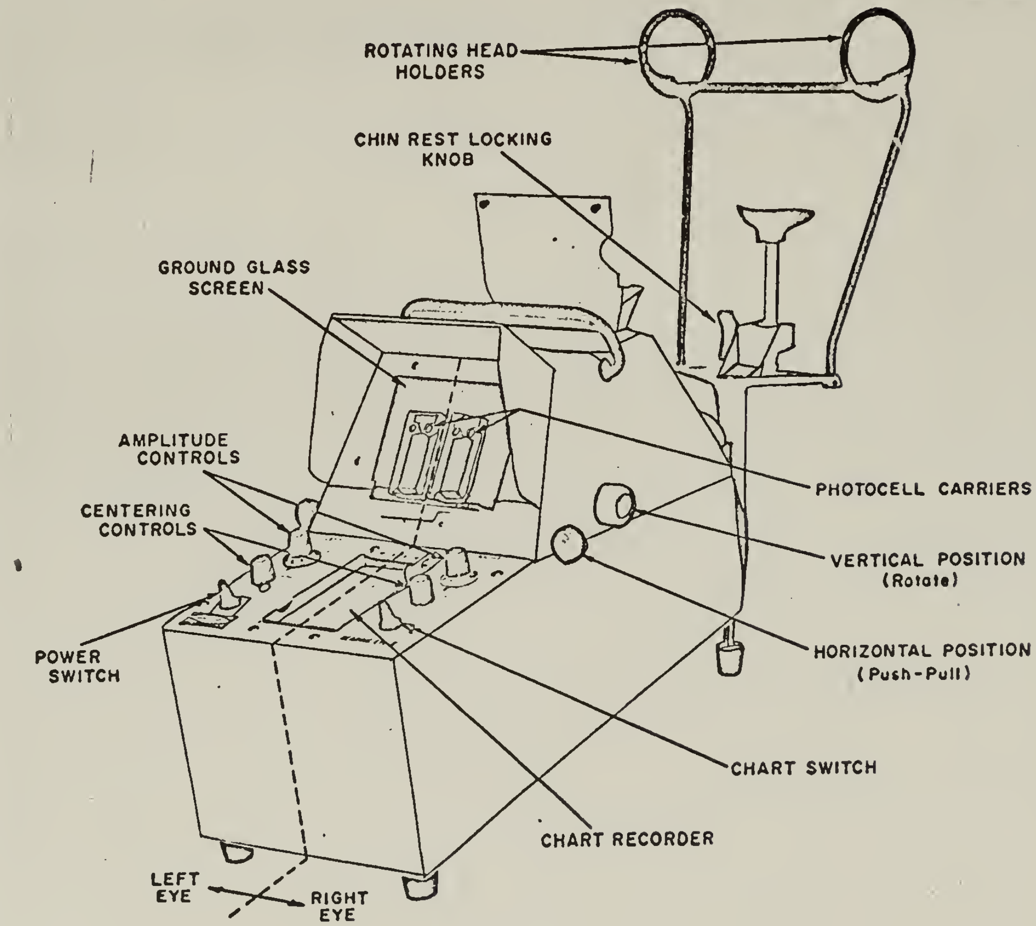


FIGURE 1b

Eye-Trac Descriptive Diagram

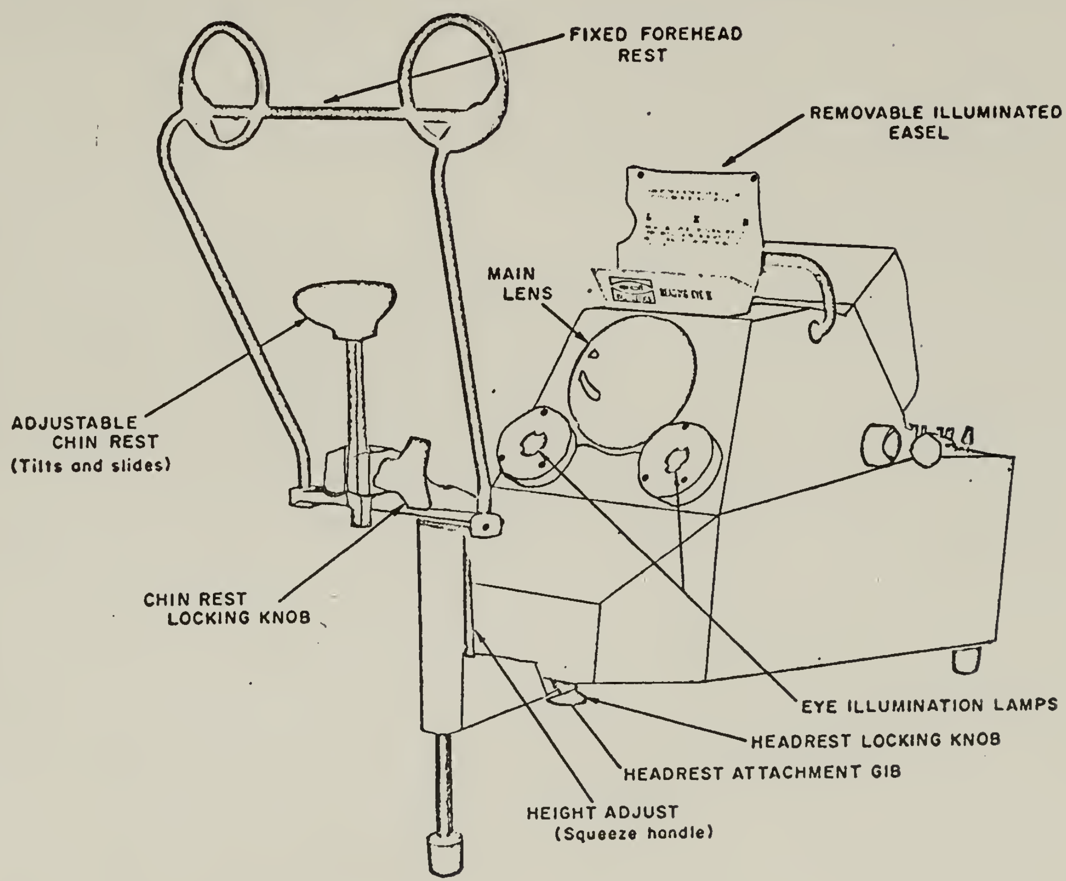


FIGURE 1c

Eye-Trac Descriptive Diagram

obtained optically with no attachments to the subject (see Figure 1a). Using an optical sensing scheme, an image of the subject's eyes is presented to the experimenter for sensor (photocell) positioning. The experimenter positions photocells strategically on an image of the subject's eyes (see Figure 2). As the eye moves, the photocells sense changes in the light impinging upon them (due to the difference in reflectivity between the iris and the sclera) and generate signals proportional to the eye movement (see Figure 3). These signals are amplified electronically and used to drive the pen of a chart recorder.

The Eye-Trac is a recent development of Biometrics Company, and the only data on the instrument's accuracy comes from Biometrics Inc. (see Table IV). According to Biometrics Inc., the Eye-Trac will resolve horizontal eye movements to better than one-half of one degree, and photocell response time is an analog of intensity change.

The Techni-Rite Model TR722 Dual Channel High Speed Recorder (see Figure 4) was used to record the output of the Eye-Trac. The TR722 is a completely self-contained two-channel recorder designed to record up to 125 cps at 50 mm per second. It records by the pressure-thermal method, which requires heated writing styli and heat-sensitive chart paper. According to Techni-Rite Electronics, Inc., the TR722 has a rise time of five milliseconds, for 10 to 90 percent full-scale deflection. For specifications see Table V.

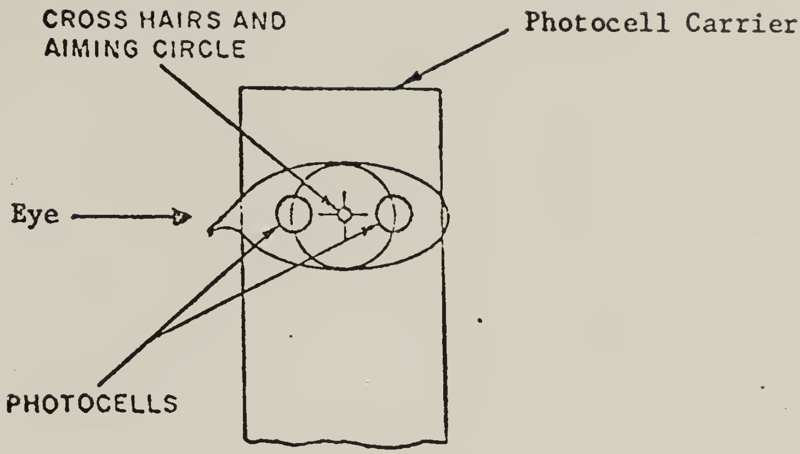


FIGURE 2

Sensor Positioning

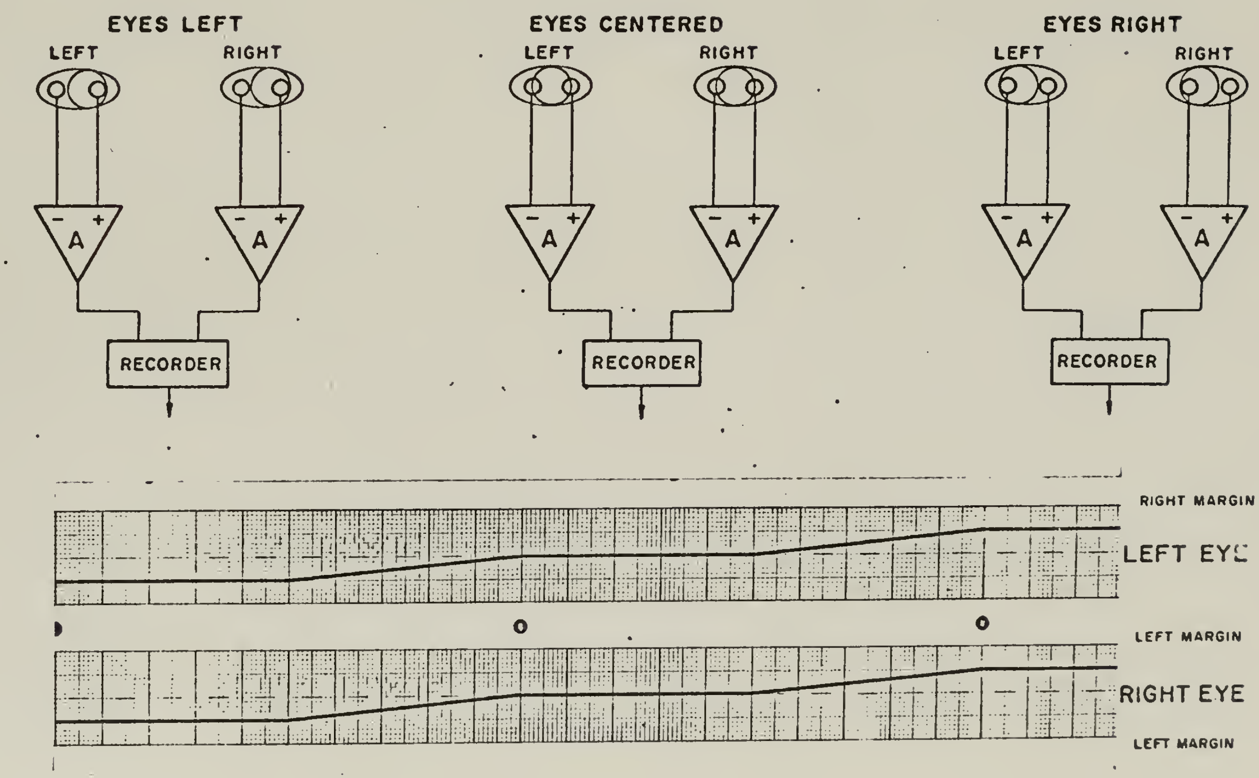


FIGURE 3

Photoelectric Sensing Technique

TABLE IV

SPECIFICATIONS OF THE EYE-TRAC ACCORDING TO BIOMETRICS INC.

Power:	105-125 VAC @ 60 Hz, 1 amp. (210-250 VAC @ 50 Hz available)		
Weight:	25 pounds		
Maximum Dimensions:	31" long x 23" high x 11" wide		
Headrest:	Fully adjustable with both gross and fine elevation adjustments, chin cup tilt adjustment, and built-in lateral head supports		
Eye Illumination:	IR-filtered incandescent lamps 15 cp, GE 94 IF		
Photo Sensors:	Silicon photocells		
Electronics:	Solid-state, plug-in printed circuit boards		
Recorder:	Response - 40 Hz Paper speed - 10 mm/sec Medium - Heat-sensitive paper 2.5" wide, 100' roll		
Output Signal:	Typical range - ± 3.0 V Typical scale - 300 mv/degree Output impedance - 1000 ohms		
		Horizontal	Vertical[1]
Resolution:		1/2°	1°
Range from Center:	Linear	± 10°	± 10°
	Usable	± 20°	± 15°
Response:	40 Hz/sec or 30 ms with recorder, 100 Hz/sec or 2 ms without recorder (electrical output signal)		
Artifacts:	Blinks, head movements, ambient light variation		

[1] Applies to units with vertical modification.

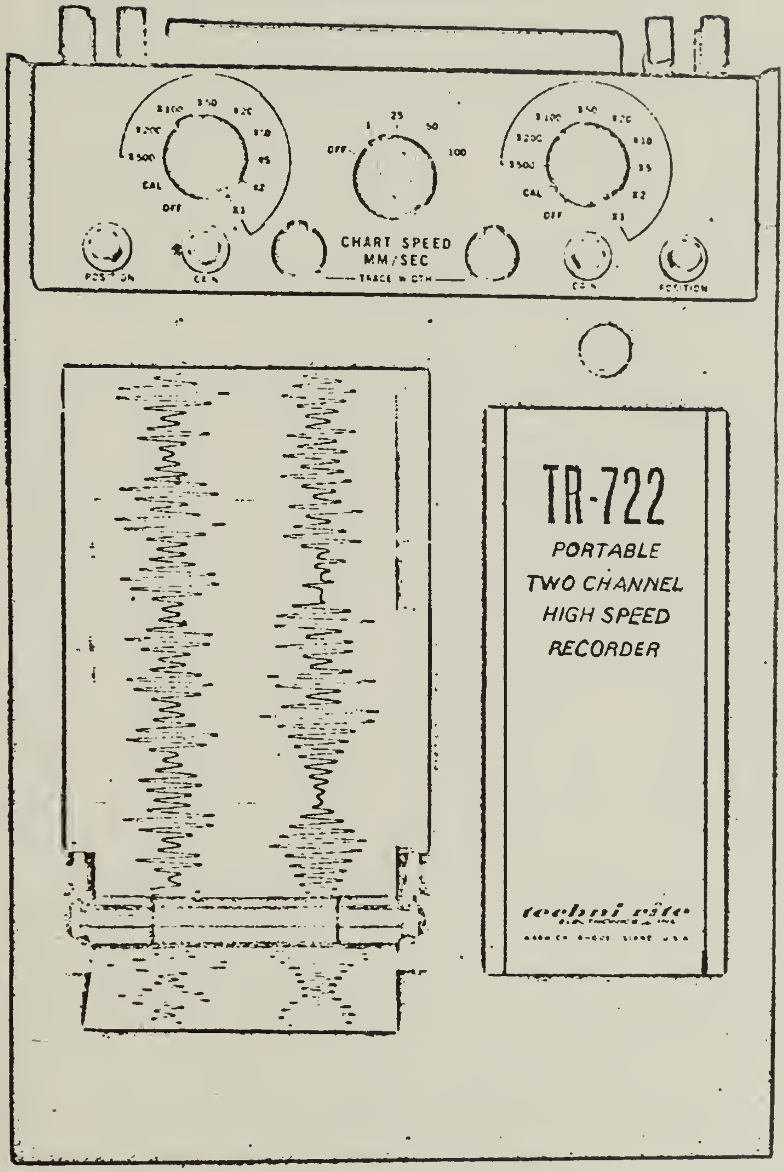


FIGURE 4

Model TR-722
Dual Channel High Speed Recorder

TABLE V

TR722 SPECIFICATIONS

Number of Channels:	Two
Frequency Response:	DC to 125 cps
Rise Time:	5 milliseconds, 10% to 90% of full scale (20 divisions)
Voltage Sensitivity:	10 millivolts per chart division
Current Sensitivity:	10 microamperes per chart division
Input Configuration:	Single-ended and floating
Voltage Input Impedance:	500K ohms
Current Input Impedance:	1000 ohms
Stability:	Less than 1/3 chart line per 8 hours
GAIN Control (Locking):	Continuous, 20: 1 range
Attenuator:	Nine positions, 500: 1 range
POSITION Control (Locking):	Positions stylus to any point on the chart
Trace Width Control:	Automatic with chart speed, also manual
Linearity (Overall):	Within 0.5 chart divisions
Power Required:	105-125 VAC, 60 cps
Dimensions:	10-1/8" wide x 4-3/4" deep x 15-1/2" long
Weight:	35 pounds, approximately

Scoring

For each sentence read by each subject, a chronological record was made of the areas fixated and the duration of each fixation. The output of the Techni-Rite Dual Channel Recorder consisted of a vertical line representing fixation time and a horizontal line which was analog to the horizontal movements of the subject's eyes. In order to identify the area of the sentence the subject was fixating, the following procedure was used.

Before each experimental sentence was presented to a subject, the experimenter calibrated the Eye-Trac. The experimental sentence and the calibration stimuli were photographed on 35 mm slides. On each slide the calibration figures (1, X, 2) were positioned so that the number 1 appeared one-half inch directly above the first character of the experimental sentence, the number 2 appeared 64 characters to the right, and the X appeared in the middle above the experimental sentence. A shutter was used to expose the calibration figures before exposing the experimental sentence. While the calibration figures were being presented, the subject was asked to look at them and the experimenter then adjusted the amplitude control of the Eye-Trac so that the high-speed recorder "read" full-scale deflection when the subject looked between the calibration figures 1 and 2. Since the distance between the calibration figures was known (64 characters) and since the full-scale deflection of the pen on the high-speed recorder was known, the parts of the sentence fixated by the subject could be determined by direct proportion. It was assumed that when subjects reported looking at (fixating) the calibration stimuli, they were using foveal vision.

CHAPTER III

RESULTS

Major Hypothesis I

For the linguistically-defined area of the experimental sentences which contained the verb, it was predicted that there would be a significantly greater frequency of forward and backward fixations as compared to either the area of the subject or the area of the object of the verb. An analysis of variance testing the fixation frequencies among the subject, verb, and object areas for all experimental sentences showed no significant results (see Table VI and Figures 5a and 5c). Thus the hypothesis is not confirmed.

Additional Results Using Frequency of Fixation

Significant differences ($p < .001$) were found when mean number of forward fixations was compared to mean number of backward fixations across linguistically-defined areas of all experimental sentences (see Figure 6). No significant interactions were found between position of prepositional phrase insertion, linguistically-defined part, and/or fixation direction (i.e., forward or backward) when fixation frequencies were used as the dependent variable.

Major Hypothesis II

For the linguistically-defined areas of the selected experimental sentences, it was predicted that there would be differences in the

TABLE VI

Analysis of Variance for Frequency of Fixation Used as the Dependent Measure (A = Prepositional Phrase Placement; B = Linguistically-defined Area; C = Direction of Fixation; S = Subjects)

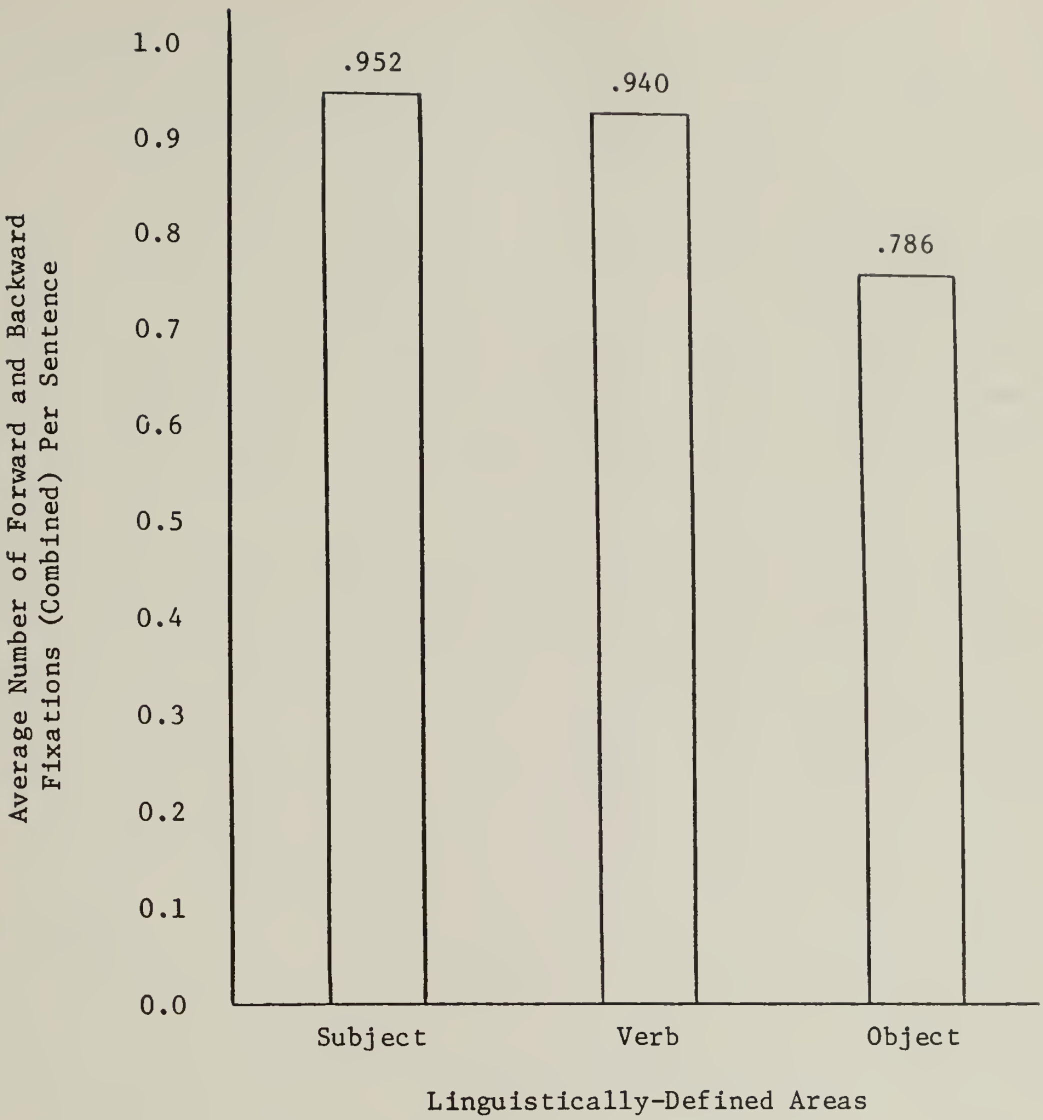
Source	Corrected df	Mean Square	F Ratio
Main effects			
A	3	12.20	2.58
AS	27	4.72	
B	2	17.32	3.24
BS	18	5.35	
C	1	1057.00	196.40***
CS	9	5.38	
Interaction effects			
A x B	6	7.84	1.61
A x B x S	51 (3 df lost)[a]	4.85	
A x C	3	2.82	.42
A x C x S	18 (9 df lost)	6.71	
B x C	2	12.83	1.64
B x C x S	12 (6 df lost)	7.80	
A x B x C	6	7.80	1.08
A x B x C x S	36 (18 df lost)	7.19	

Cell Means

A:	3.93	4.71	4.94	4.28	
B:	4.76	4.70	3.93		
C:	6.56	2.36			
D:	3.13	5.49	6.05	3.26	4.96
	5.00	4.05	4.45	5.08	3.17

[a] Degrees of freedom were lost because subjects did not always look at (fixate) every level of the independent variables.

*** $p < .001$



<u>FIGURE 5a</u>

Average frequency of forward and backward fixations (combined) to the linguistically-defined areas (i.e. subject, verb, object of the verb) of experimental sentences. Differences are not significant.

Quantifications given indicate the average number of times subjects looked at (fixated) a linguistically-defined area. For example: .952 indicates for all subjects the average number of times per sentence they fixated the subject area of the sentence. Because some subjects did not look at the subject area, the overall average for fixating the subject area is less than 1.0.

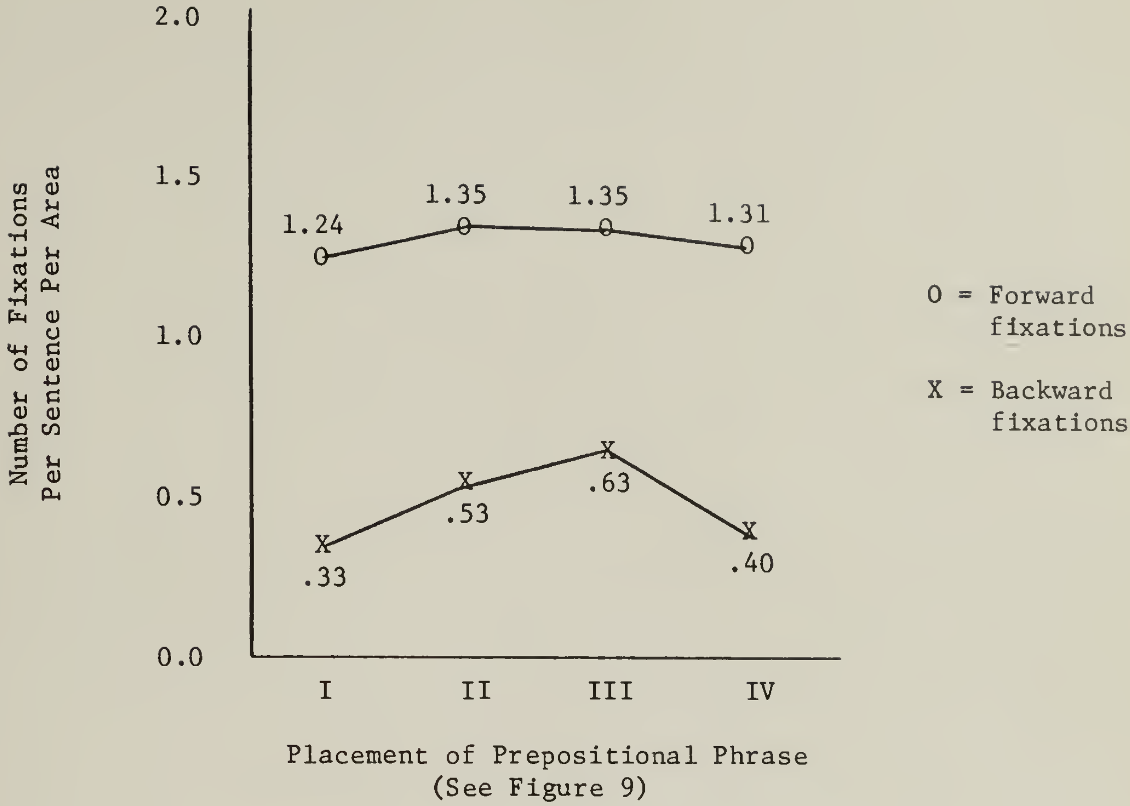


FIGURE 5b

Average number of forward and backward fixations per area per sentence for each type of prepositional phrase placement. No significant interaction.

Quantifications given indicate the average number of times subjects looked at (fixated) a linguistically-defined area. For example: 1.24 indicates for all subjects the average number of forward fixations per linguistically-defined area for all sentences where the prepositional phrase was placed in Position I. Because it was possible for some subjects to fixate some linguistically-defined areas twice in a forward direction, the quantification is greater than 1.0.

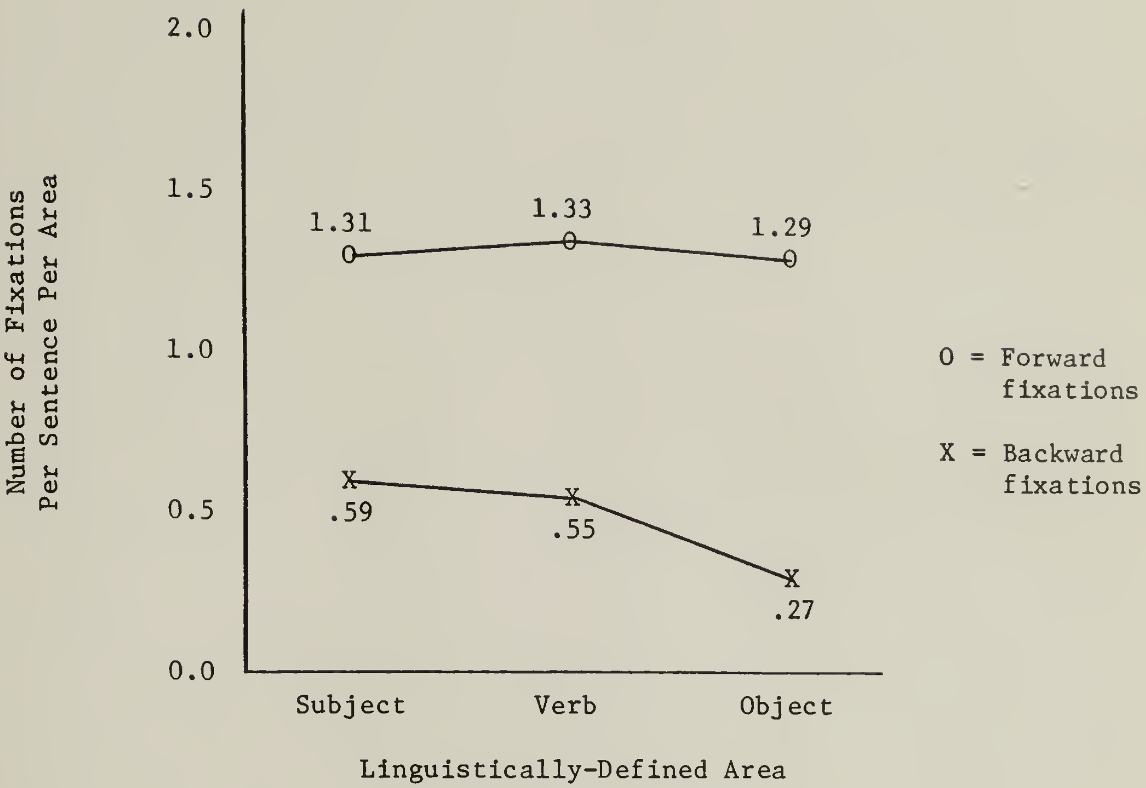


FIGURE 5c

Average number of forward and backward fixations per sentence for each linguistically-defined area. No significant interaction.

For further explanation of above quantifications, see Figures 5a and 5b.

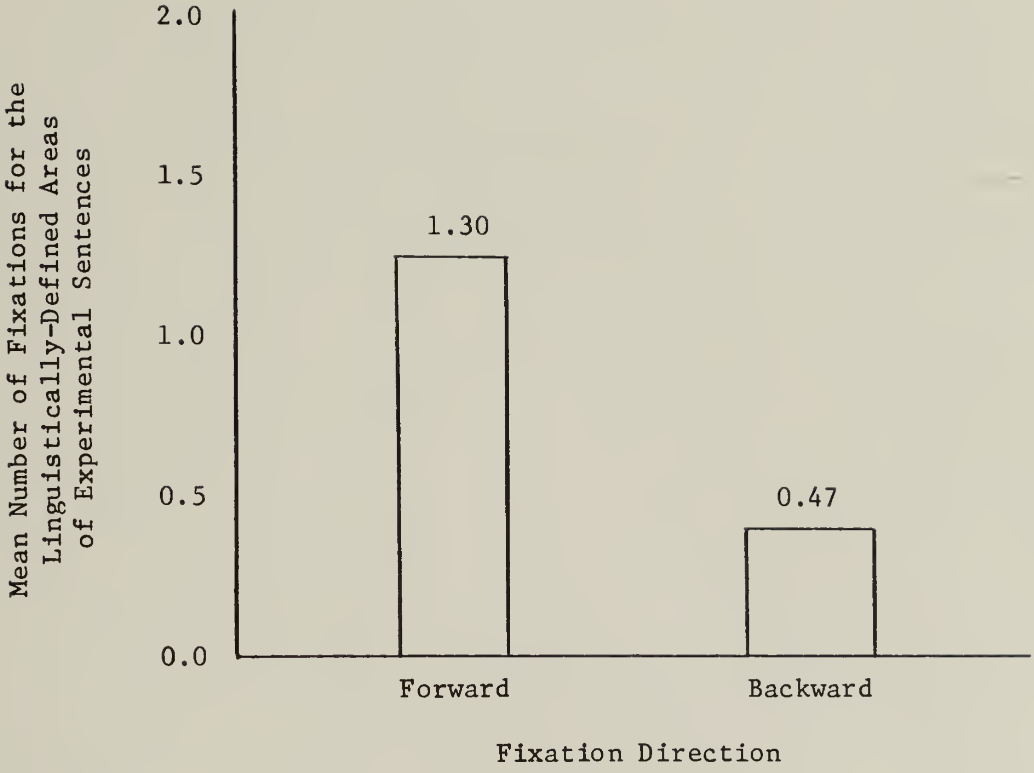


FIGURE 6

Comparison of mean number per sentence of forward and backward fixations across linguistically-defined areas of all experimental sentences. Differences are significant ($p < .001$).

average durations of forward and backward fixations combined. An analysis of variance testing the average duration of forward and backward fixations combined, for differences between areas of the subject, verb, and object for all experimental sentences, showed no significant differences (see Table VII and Figure 7). Thus the hypothesis is not confirmed.

Additional Results Using Mean Fixation Time

Significant differences ($p < .01$) were found between average duration of forward and backward fixations for all linguistically-defined areas of the experimental sentences (see Figure 8).

Significant differences ($p < .001$) in average fixation duration were found between sentences which differed with respect to the location of insertion of a prepositional phrase; specifically, sentences which had a prepositional phrase inserted between the verb and object were found to have longer average fixation durations than other experimental sentences when forward and backward fixations combined were analyzed across the linguistically-defined areas of the four types of sentences which had other prepositional phrase placement (see Figure 9).

A two-way interaction of linguistically-defined area by direction of fixation was found to be significant ($p < .01$). Figure 10 shows that the average backward fixation time for the object area of the sentence is shorter (182.6 milliseconds) than the average forward fixation time for the object area of the sentence (256.4 milliseconds).

Figure 11 shows the interaction ($p < .001$) of average fixation time (forward and backward combined) to the linguistically-defined area for

TABLE VII

Analysis of Variance for Average Fixation Time Used as the Dependent Measure (A = Prepositional Phrase Placement; B = Linguistically-defined Area; C = Direction of Fixation; S = Subjects)

Source	Corrected df	Mean Square	F Ratio
Main effects			
A	3	129.54	6.71*
AS	27	19.28	
B	2	81.23	2.78
BS	18	29.15	
C	1	360.64	8.81**
CS	9	40.93	
Interaction effects			
A x B	6	85.69	4.94***
A x B x S	51 (3 df lost)[a]	17.36	
A x C	3	129.54	4.20 (p<.025)
A x C x S	18 (9 df lost)	30.80	
B x C	2	386.34	13.86***
B x C x S	12 (6 df lost)	27.87	
A x B x C	6	35.20	1.38
A x B x C x S	36 (18 df lost)	25.46	

Cell Means

A:	20.93	21.69	24.27	21.61	
B:	21.22	23.21	21.95		
C:	23.35	20.90			
S:	23.40	24.27	22.46	23.67	21.03
	22.89	23.05	18.54	18.47	23.50

[a] Degrees of freedom were lost because subjects did not always look at (fixate) every level of the independent variable.

* $p < .05$
** $p < .01$
*** $p < .001$

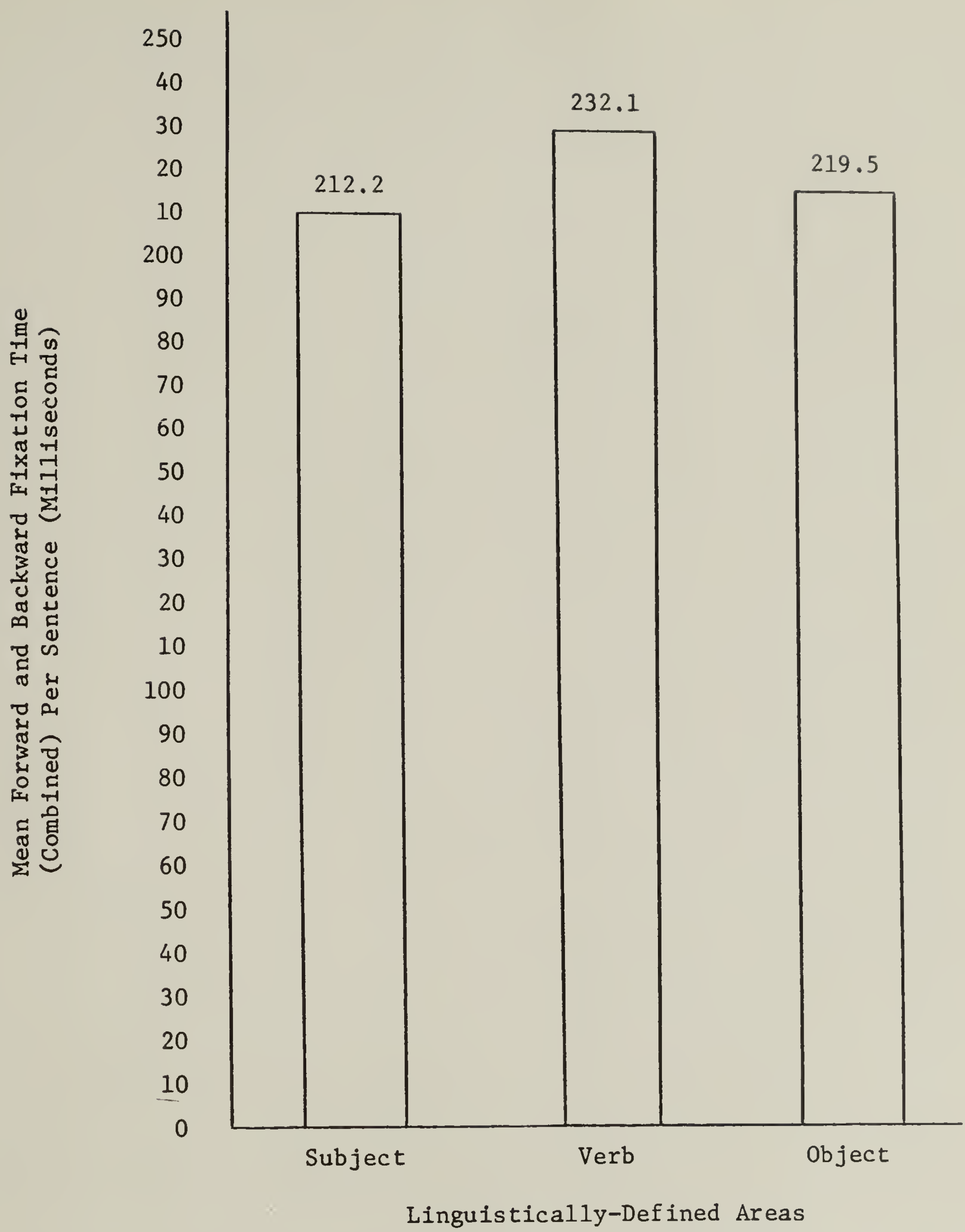


FIGURE 7

Mean fixation time for forward and backward fixations (combined) to the linguistically-defined areas (i.e. subject, verb, object of the verb) of all experimental sentences. Differences are not significant.

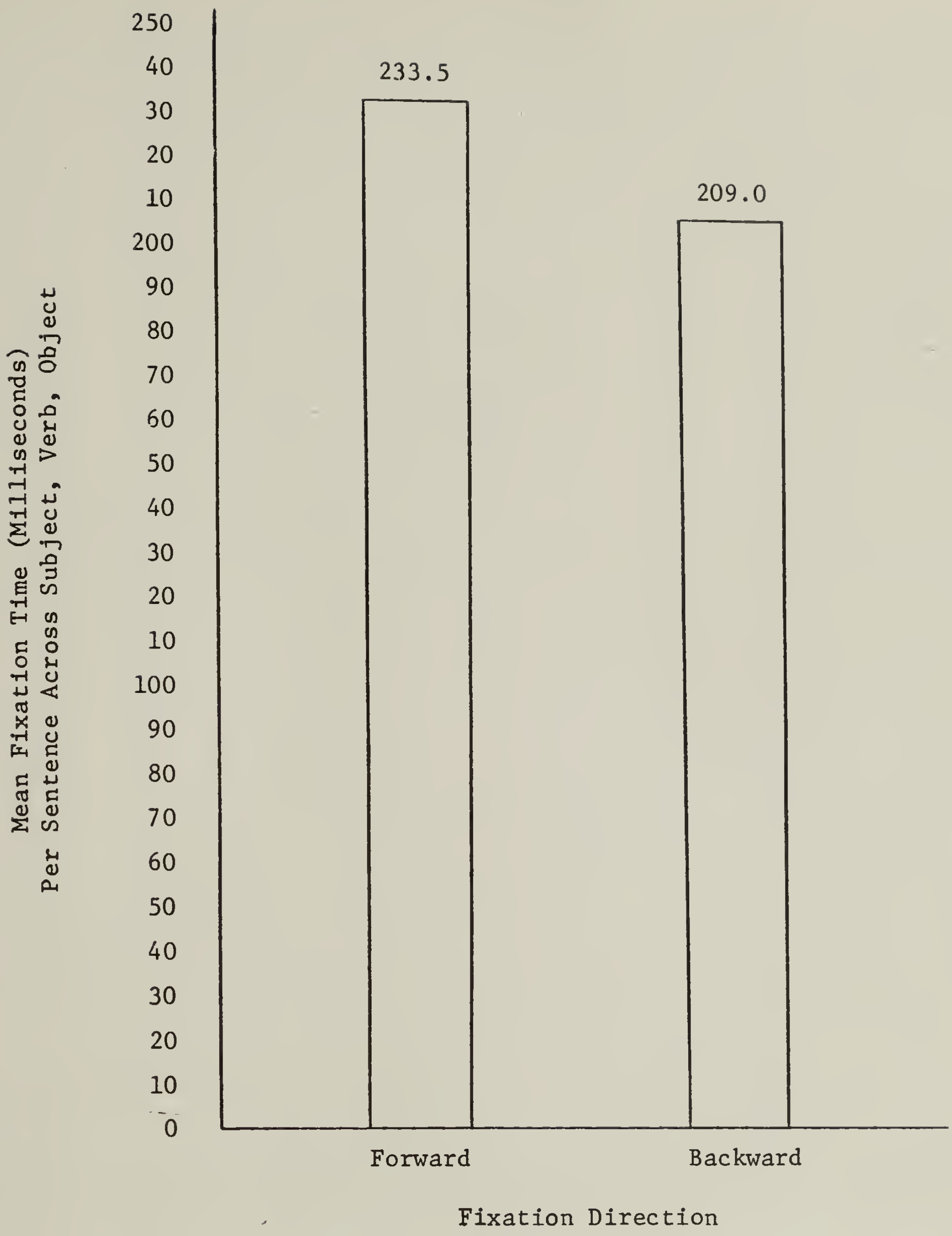


FIGURE 8

Mean fixation time for forward and backward fixations across the linguistically-defined areas (i.e. subject, verb, object of the verb) of all experimental sentences. Differences are significant.

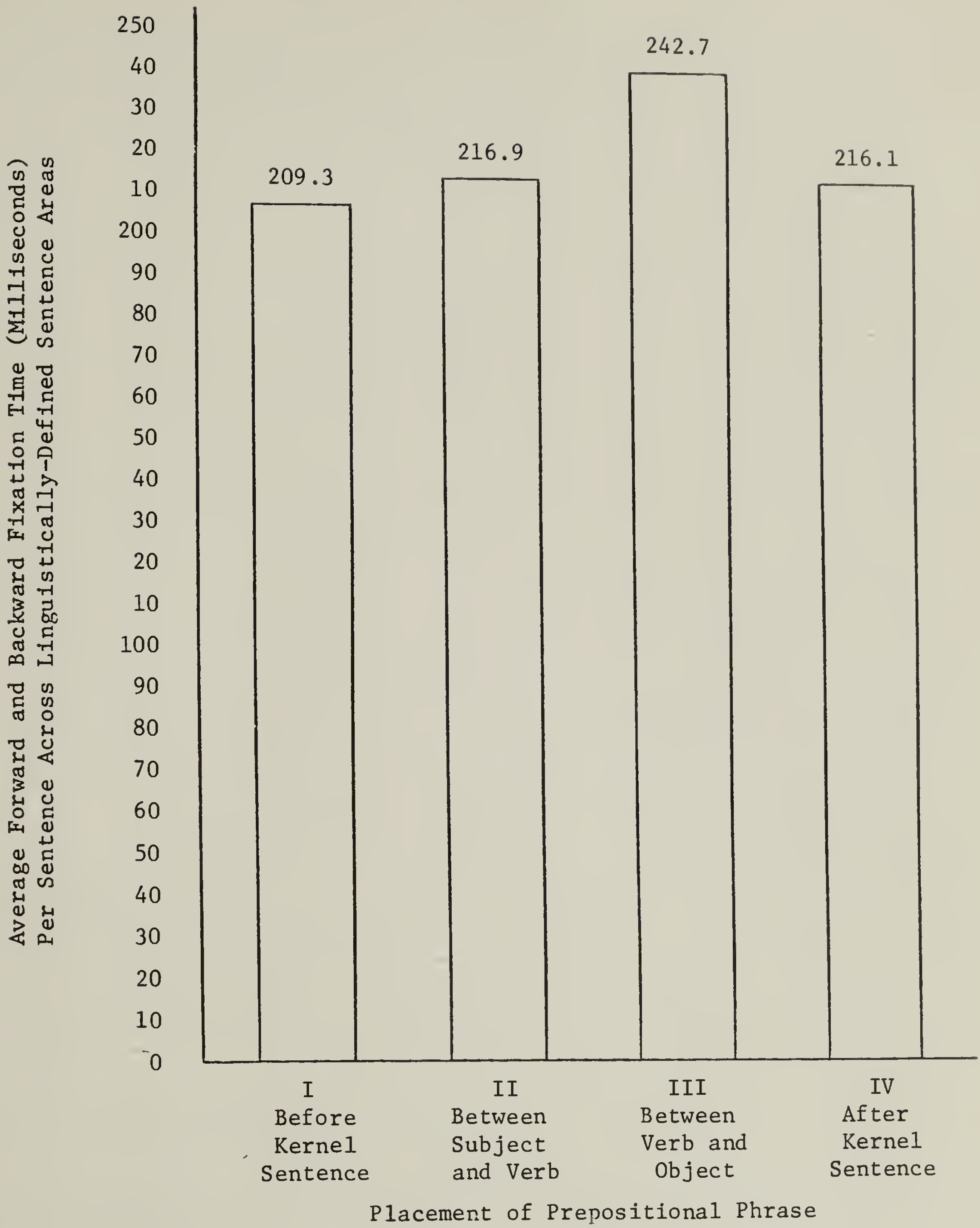


FIGURE 9

Average forward and backward fixation time (combined) across linguistically-defined areas, for the four placements of a prepositional phrase. Placement III is significantly different ($p < .001$) than Placement I, II, or IV.

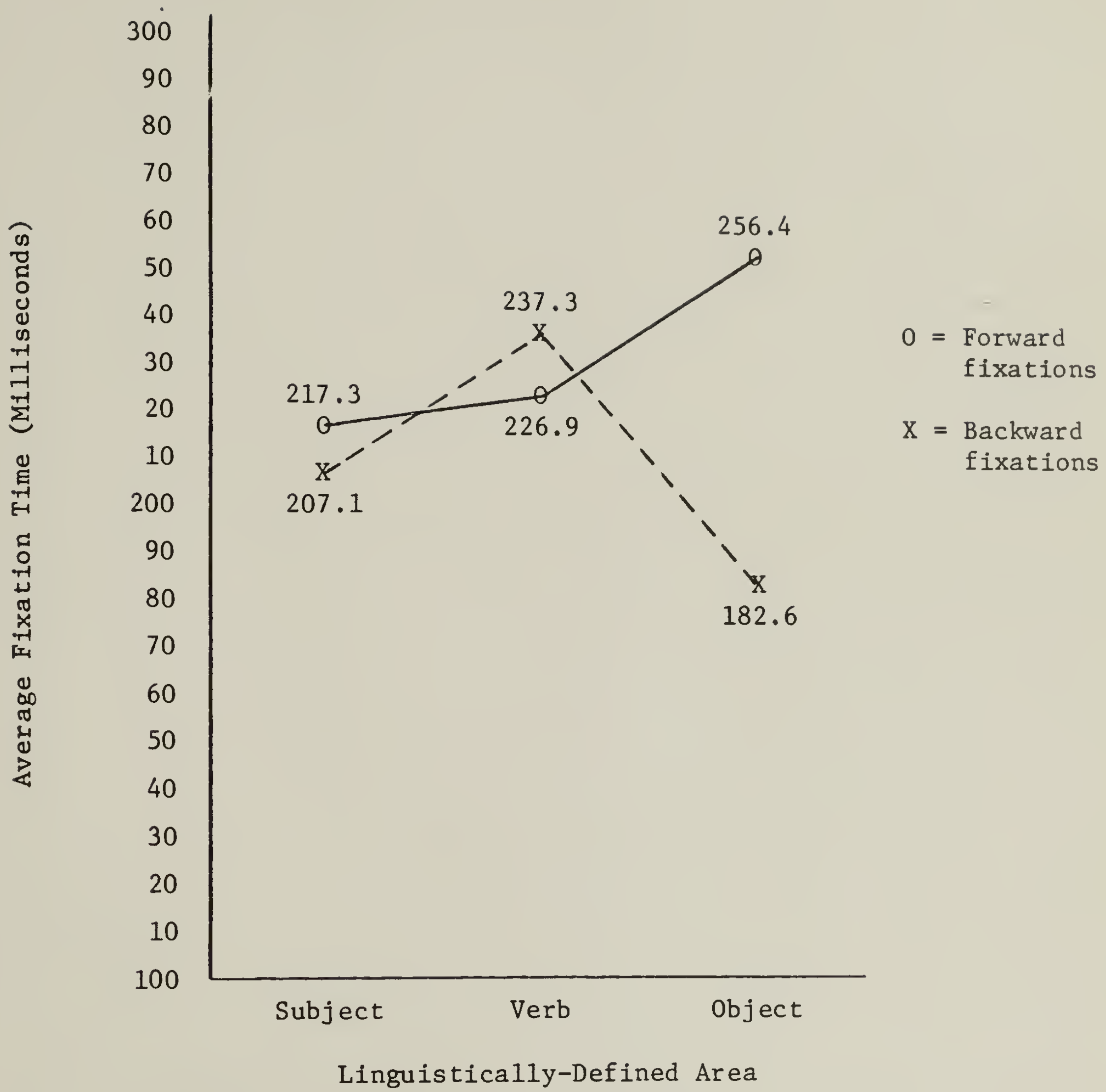


FIGURE 10

Average fixation time interaction of direction of fixation by linguistically-defined area.

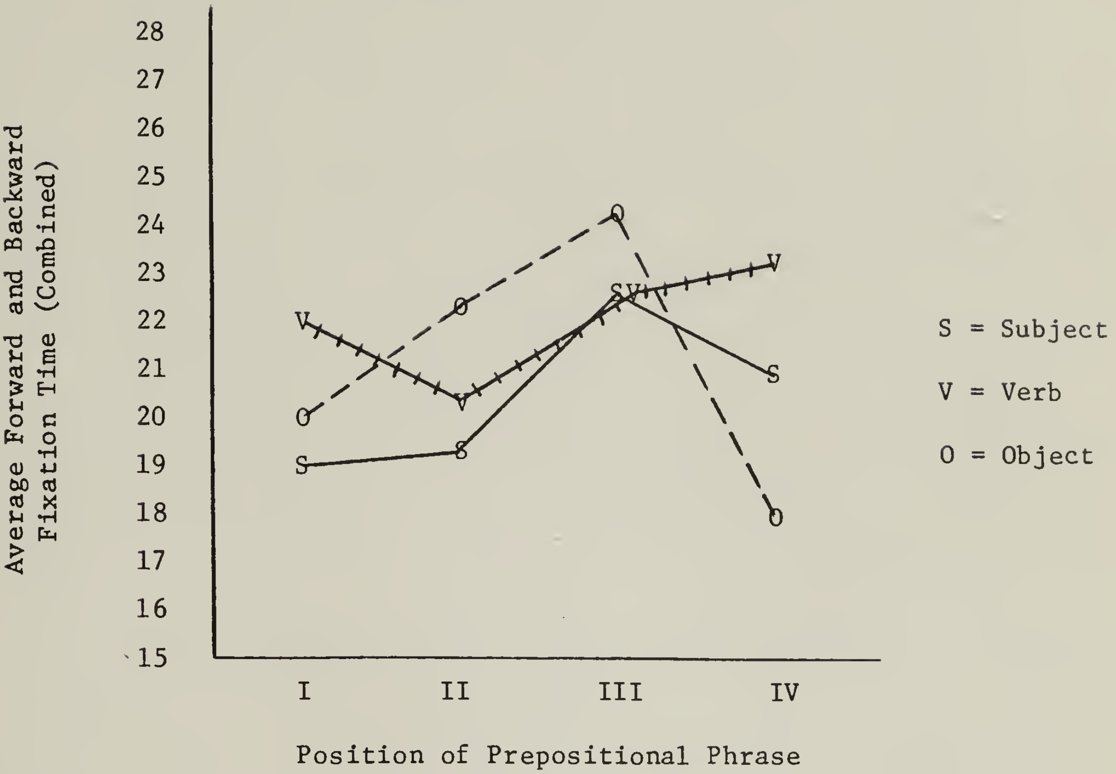


FIGURE 11

Average fixation time interaction of linguistically-defined area by position of prepositional phrase for forward and backward fixations combined.

the four positions of a prepositional phrase. For Sentence Type I (e.g., "In the store the new pants fit the man"), prepositional phrase positioned at the beginning of the experimental sentence, and Sentence Type IV (e.g., "The new pants fit the man in the store"), prepositional phrase positioned after the experimental sentence, the verb area had the highest average fixation time (forward and backward combined). For Sentence Type II (e.g., "The new pants in the store fit the man"), prepositional phrase inserted between the subject and verb, and Sentence Type III (e.g., "The new pants fit in the store the man"), prepositional phrase inserted between the verb and object, the object area had the highest average fixation time. For Sentence Type IV the object area had the lowest average fixation time.

Figure 12 shows the interaction ($p < .025$) of average fixation time for positions of the prepositional phrase across forward and backward fixations for all linguistically-defined areas of the experimental sentences. The highest average <u>backward</u> fixation time is shown for Sentence Type III and the lowest average <u>backward</u> fixation time is shown for Sentence Type I, while the highest average <u>forward</u> fixation time is shown for Sentence Type I and the lowest average <u>forward</u> fixation time is shown for Sentence Type IV.

Exploratory Hypothesis

For the three position-defined eye fixations, it was predicted that there would be no difference in average fixation durations. Table VIII and Figure 13 show the results of comparing average duration for each

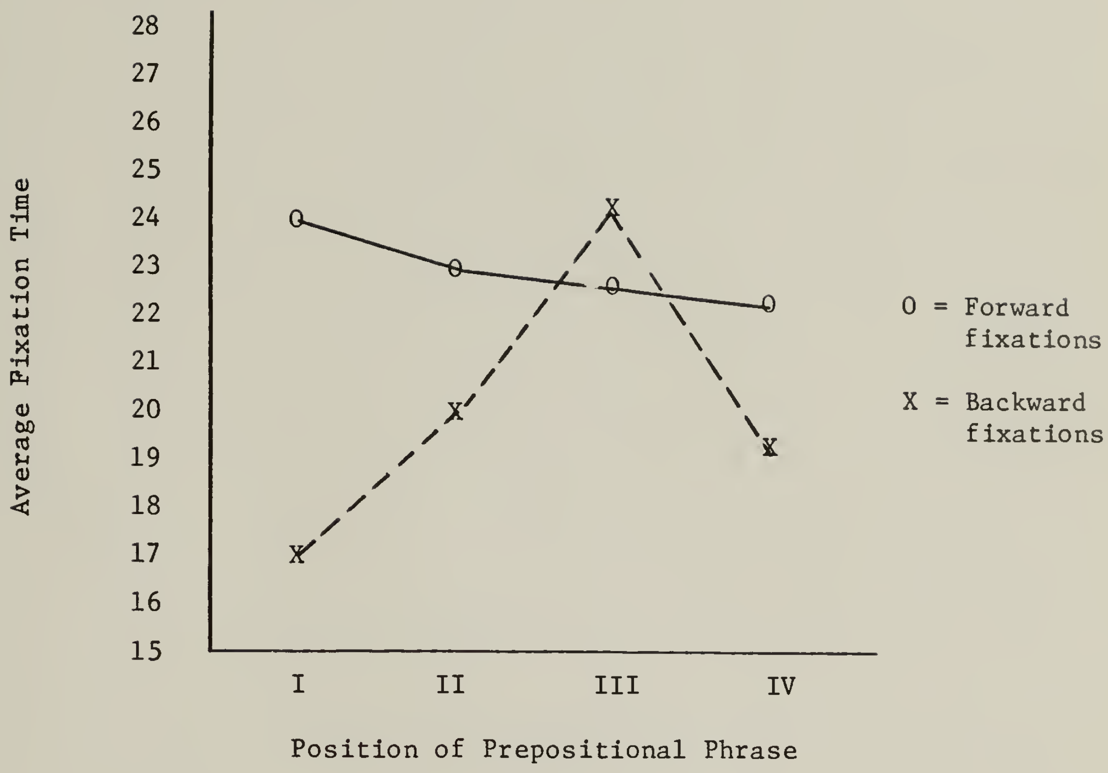


FIGURE 12

Average fixation time interaction of position of prepositional phrase by fixation direction for all linguistically-defined areas.

TABLE VIII

Analysis of Variance for Testing the Exploratory Hypothesis (A = Prepositional Phrase Placement; B = Position-defined Fixations; S = Subjects)

Source	df	Mean Square	F Ratio
A	3	83.66	1.92
AS	27	43.53	
B	2	5.53	.12
BS	18	47.11	
AB	6	45.55	1.01
ABS	54	45.02	

Cell Means

A:	21.29	19.64	23.66	21.00
B:	21.81	21.28	21.10	

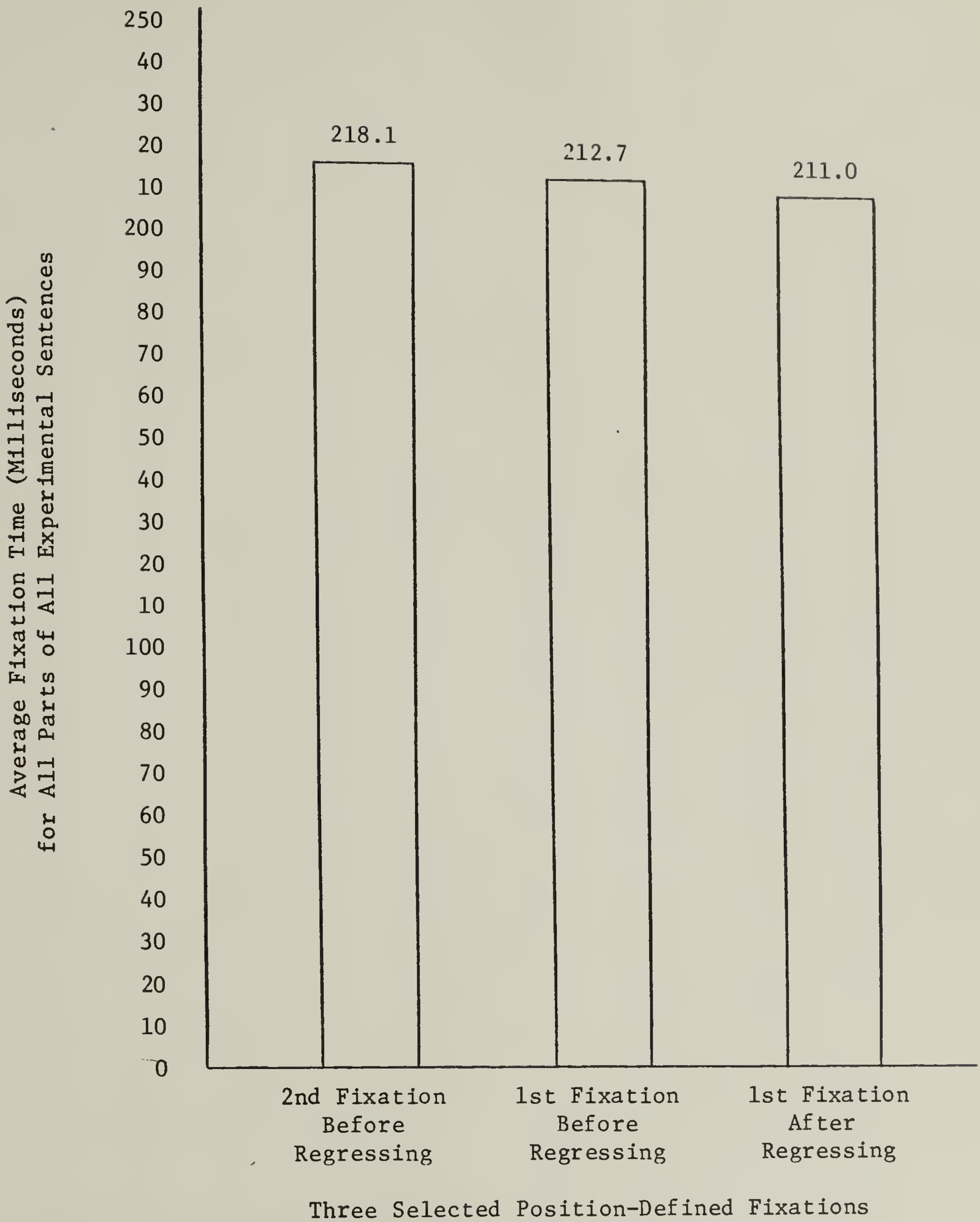


FIGURE 13

Average fixation time for the three selected position-defined fixations taken from all experimental sentences without regard to linguistically-defined area. Differences are not significant.

type of fixation. No significant differences were found; average fixations for the three kinds of fixations were within eight milliseconds of each other. Thus the hypothesis is accepted.

Non-Hypothesized Results

In addition to analyzing average duration and number of forward and backward fixations for the types of experimental sentences (position of prepositional phrase) by linguistically-defined areas, an analysis of total fixation time was conducted. This analysis parallels the findings of the analysis of duration and number of fixations analysis, since total fixation time for any given area of a sentence can be reflected by either fixating "more times" or fixating "longer." Table IX presents this analysis.

Results of the analysis of total time are as follows:

1) Main effect for type of sentence. Figure 14 shows that total time spent fixating the areas of the subject, verb, and object of the verb was greater for Sentence Type III, prepositional phrase inserted between verb and object ($p < .05$), than for Sentence Type I, II or IV.

2) Main effect for fixation direction. Figure 15 shows that more time was spent in forward fixation compared to backward fixation across sentence types and linguistically-defined areas ($p < .001$).

3) Interaction effect of linguistically-defined areas by fixation direction. A two-way interaction effect is shown by Figure 16. A greater amount of time was spent in forward rather than backward fixation for the object area of the sentence ($p < .01$) when compared to

TABLE IX

Analysis of Variance for Total Fixation Time Used as the Dependent Measure (A = Prepositional Phrase Placement; B = Linguistically-defined Area; C = Direction of Fixation; S = Subjects)

Source	Corrected df	Mean Square	F Ratio
Main effects			
A	3	8837.25	4.25*
AS	27	2078.11	
B	2	3465.02	.91
BS	18	3774.54	
C	1	616824.65	174.30***
CS	9	3538.81	
Interaction effects			
A x B	6	3022.23	.85
A x B x S	51 (3 df lost)[a]	3534.42	
A x C	3	5292.36	1.69
A x C x S	18 (9 df lost)	3117.17	
B x C	2	21900.62	6.10**
B x C x S	18 (6 df lost)	3585.27	
A x B x C	6	5867.11	1.71*
A x B x C x S	54 (18 df lost)	3419.83	

Cell Means

A:	88.21	104.06	116.09	94.56	
B:	101.55	106.87	93.78		
C:	151.43	50.03			
S:	78.54	138.96	139.67	81.88	103.16
	117.28	97.59	79.56	91.03	79.63

[a] Degrees of freedom were lost because subjects did not always look at (fixate) every level of the independent variables.

* $p < .05$
** $p < .01$
*** $p < .001$

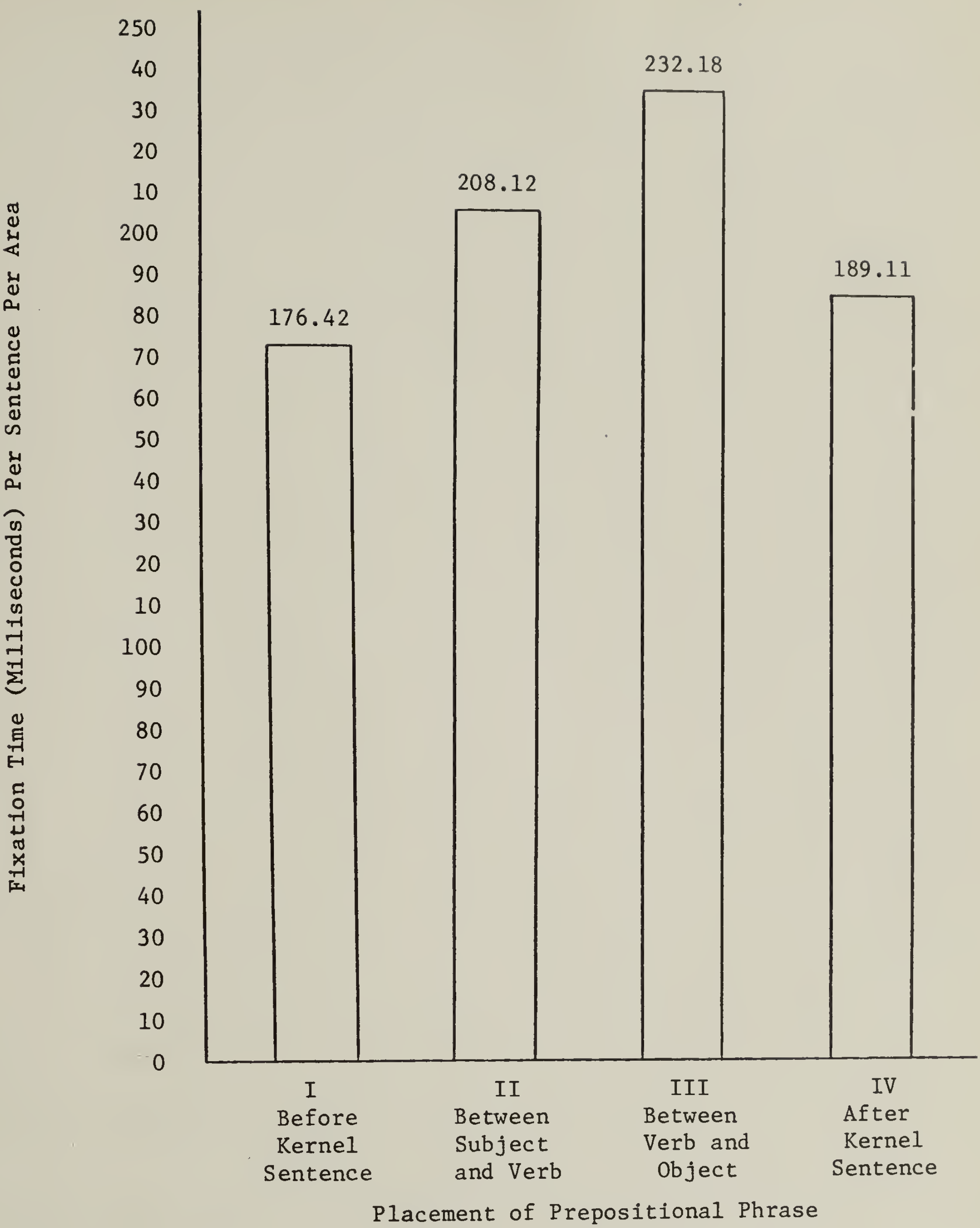


FIGURE 14

Total time spent in fixating linguistically-defined areas of the four kinds of experimental sentences which differ with regard to placement of a prepositional phrase. Sentence Type III significantly differs from Sentence Types I, II, and IV.

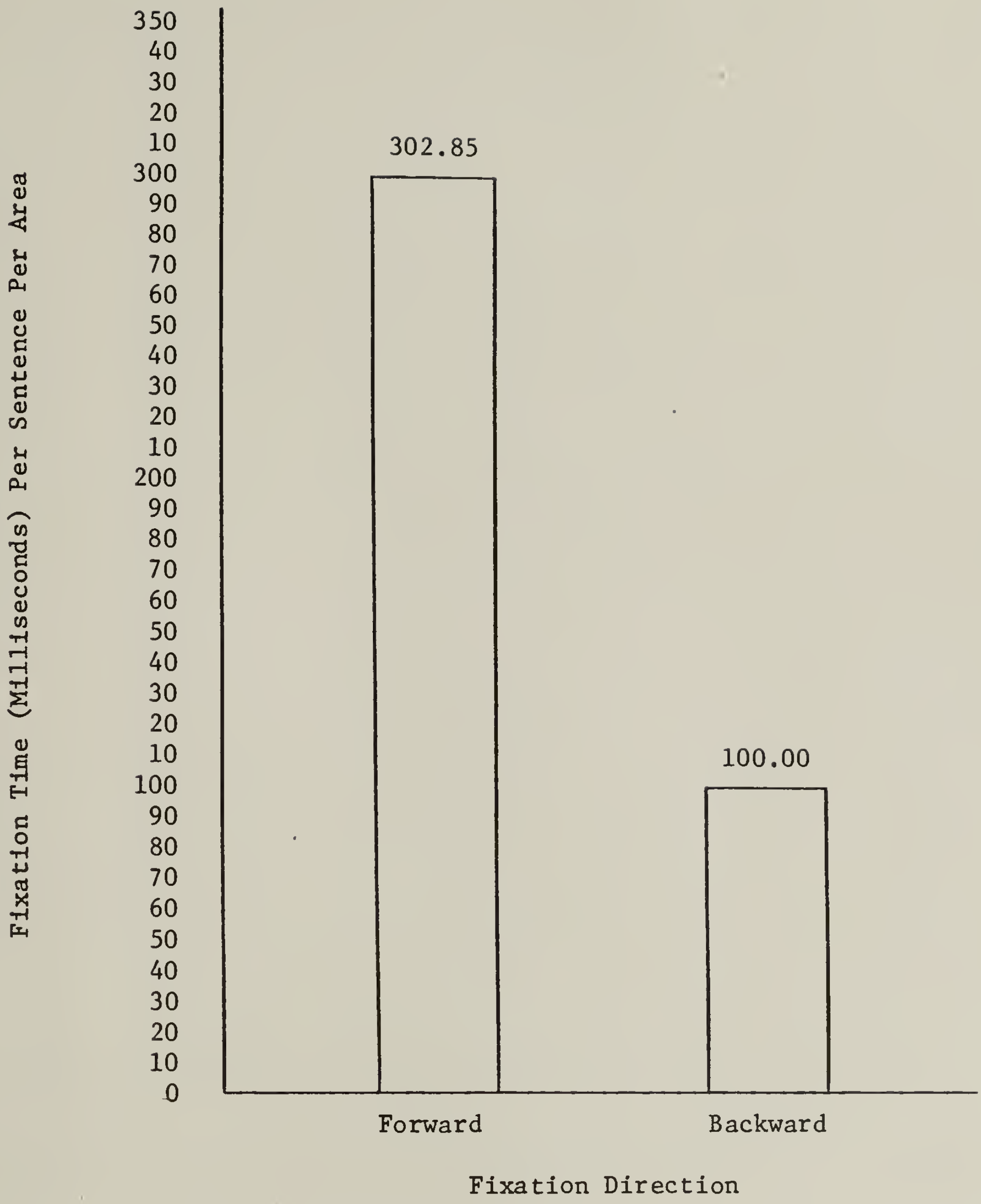


FIGURE 15

Total time spent on forward and backward fixations for the linguistically-defined parts of the four types of experimental sentences.

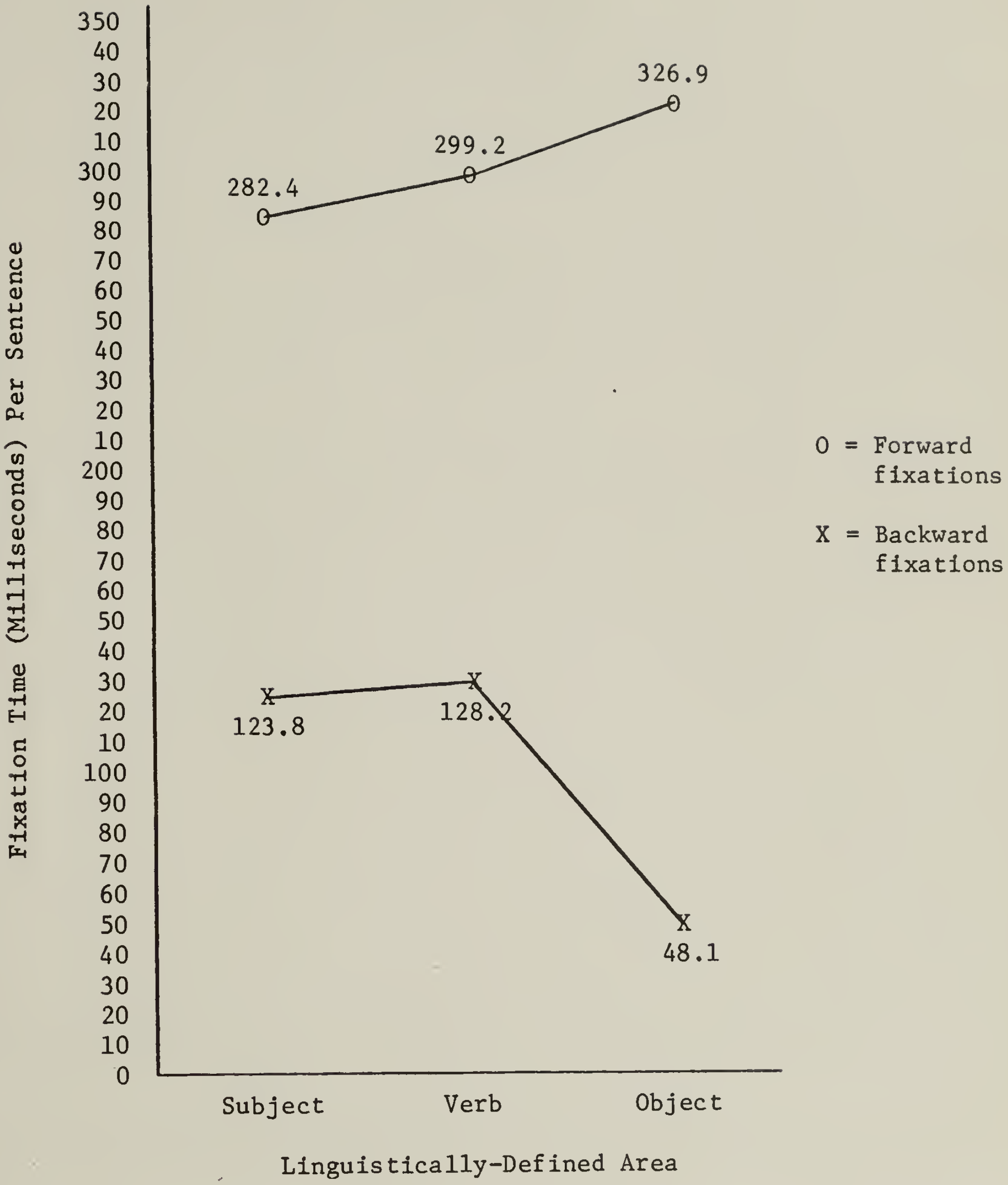


FIGURE 16

Two-way total time interaction effect of linguistically-defined areas by fixation direction.

differences between forward and backward fixations for the linguistically-defined areas of the subject and verb.

4) Interaction effect of fixation direction by position of prepositional phrase. Figure 17 shows that total time of backward fixations occurring in sentences where the prepositional phrase was inserted between the verb and object (Sentence Type III) was greater than forward fixations compared to backward and forward fixations in Sentence Types I, II, and IV.

5) Interaction effect of linguistically-defined areas by fixation direction by position of prepositional phrase. An analysis of the total time spent in forward and backward fixation to linguistically-defined areas of the experimental sentences which varied with respect to four positions of prepositional phrases is shown in Figure 18. A three-way interaction ($p < .05$) indicates:

a) A greater total time was spent in backward fixation for the area of the verb in Sentence Type III, prepositional phrase inserted between verb and object, as compared to total forward fixation time for the area of the verb in Sentence Type III.

b) Less total time was spent in forward fixation to the object area of Sentence Type IV, prepositional phrase positioned after the experimental sentence, as compared to Sentence Types I, II, and III.

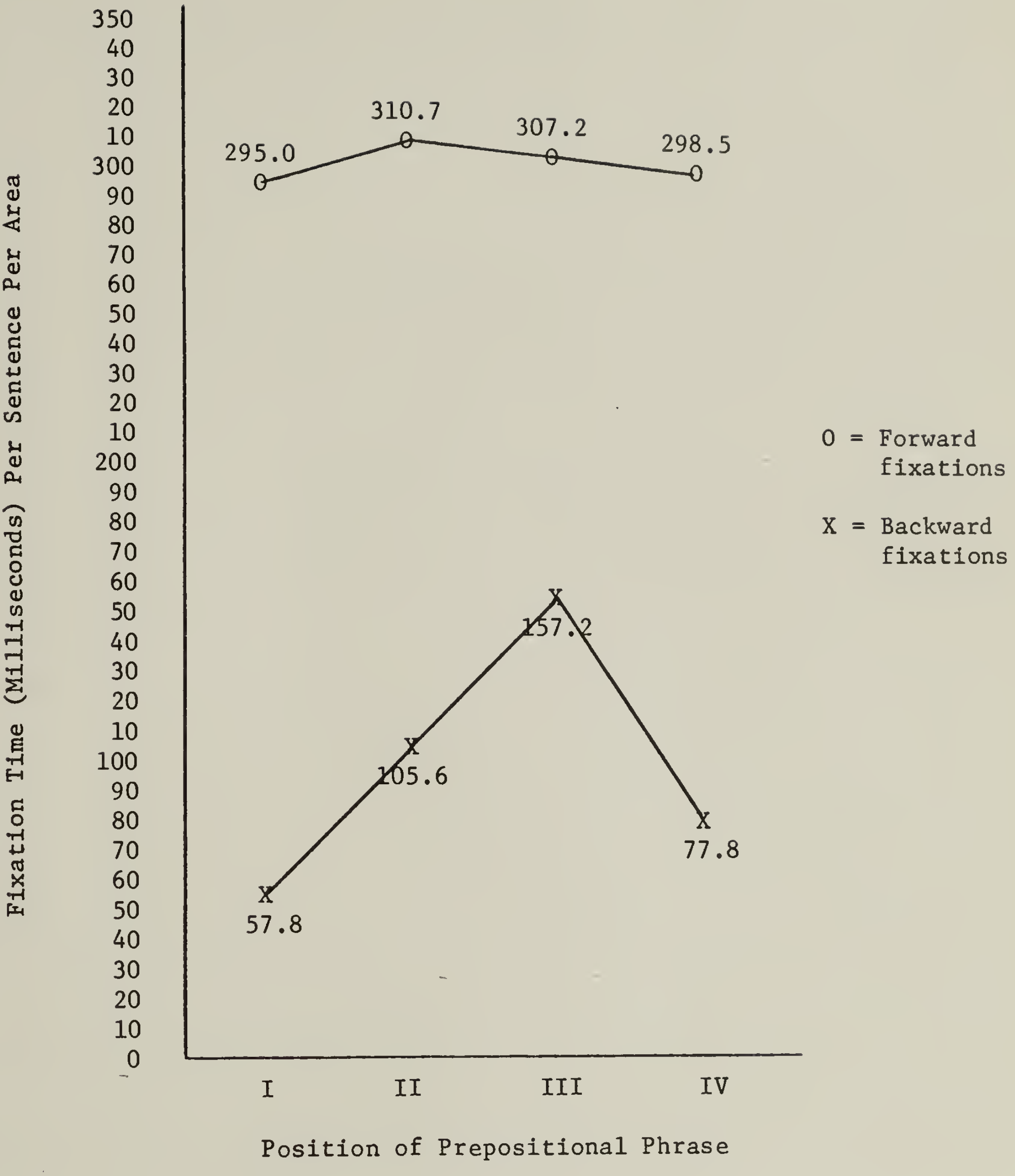


FIGURE 17

Two-way total time interaction effect of direction of fixation by position of prepositional phrase.

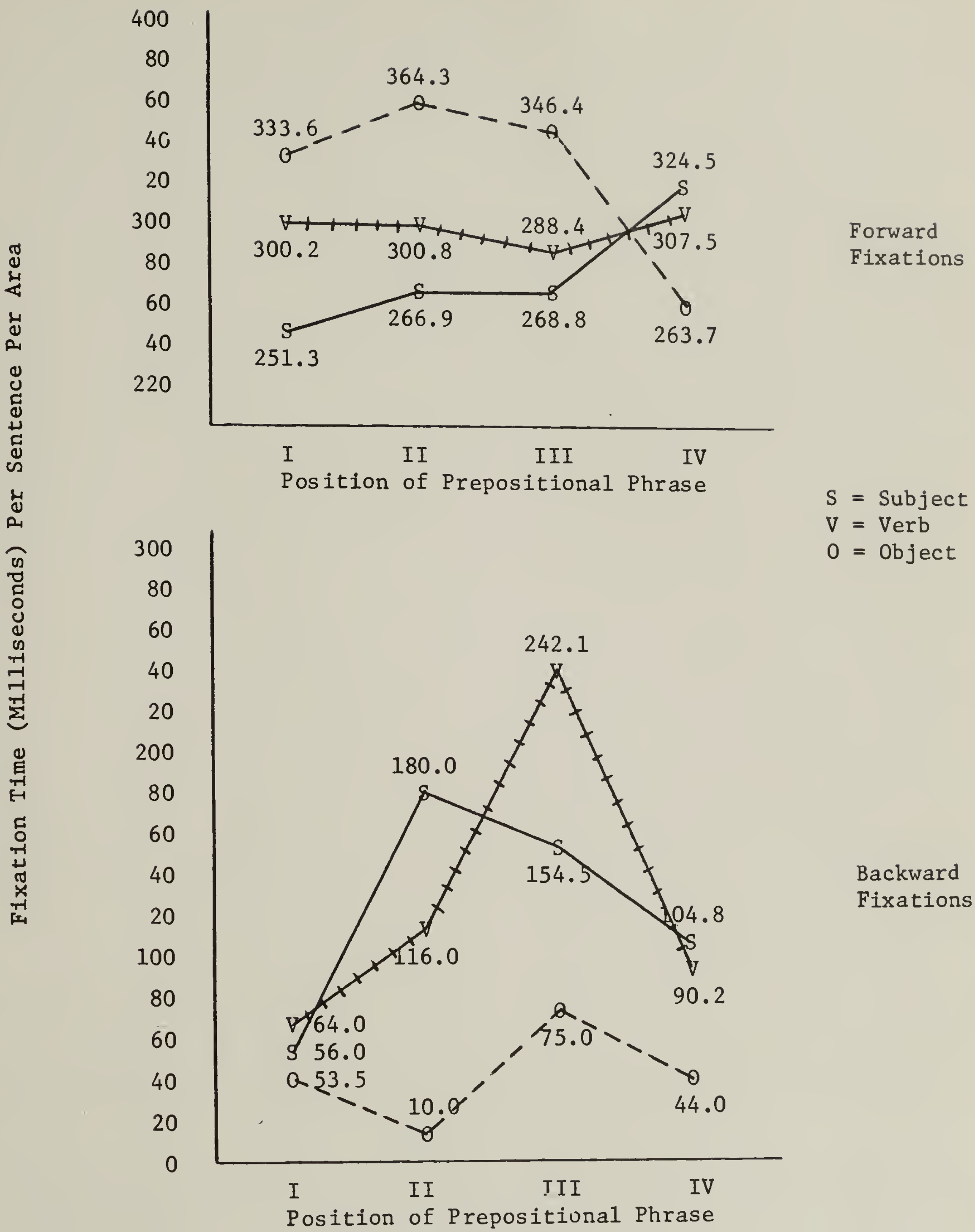


FIGURE 18

Three-way total time interaction of forward and backward fixations by linguistically-defined area by position of prepositional phrase.

CHAPTER IV

DISCUSSION

Wanat's results and the results of Fodor, Garrett and Bever (1968), Gladney and Kralee (1967), Greenberg (1970), and Kolers (1970) led to the hypothesis that not only is visual scanning behavior selective, but the area of the verb is related to visual scanning behavior. Results of the analysis presented in the previous chapter show the following about subjects in the present experiment with regard to the above hypothesis:

1) Average fixation duration used as the dependent variable. No significant differences were found between the areas of the subject, verb and object when the subject, verb and object areas were treated as main effects across fixation directions and positions of prepositional phrase. However, subjects' backward fixations had a longer average length for the area of the verb ($p < .001$; see Figure 10). For reasons of computational convenience, both forward and backward fixations were analyzed as two levels of one variable. Wanat (1970) considered forward and backward fixations as separate independent variables. If this is done in the present analysis, then the greater backward average fixation duration for the verb across the positions of the prepositional phrase becomes a main effect, paralleling Wanat's (1970) findings. However, in contrast to Wanat's finding that the verb area was related to forward fixations, the results of the present study do not show the verb to have the highest average fixation time when forward fixations are considered as a separate dependent measure and treated as main effect.

One reason for this discrepancy may be the difference in the dependent measures used. Wanat used a procedure for estimating total time. In the present analysis the dependent measure was average fixation time (see "Dependent Variables" in Chapter II).

Another reason for the apparent difference between Wanat's finding and that of the present experiment may be the inclusion in the present study of the prepositional phrases. Figure 11 shows that the average forward and backward fixation times combined are highest in the area of the object for Sentence Type III (e.g., "The new pants fit in the store the man") and that the average forward and backward fixation times combined are highest in the area of the verb for Sentence Types I (e.g., "In the store the new pants fit the man") and IV (e.g., "The new pants fit the man in the store"). The results (Figure 11) show that the insertion of a prepositional phrase between the verb and object of the verb is related to higher average forward and backward fixation time for the object area.

The implication here is that the insertion of a prepositional phrase before the object causes the subject to look longer (higher average fixation time) at the object. However, when the experimental sentence remains intact, the verb in Sentence Types I and IV has the highest average fixation time. Even though Wanat's experimental active sentences had no such interruption by a prepositional phrase, the results of the present experiment may be taken to support Wanat's finding concerning fixations occurring in the area of the verb. Further support for the suggestion that the prepositional phrase acts as an interruption is given by Figures 9 and 12, which show that the highest average fixation times occurred for Sentence Type III (e.g., "The new pants fit in the store the man").

Indeed, Figure 11 shows that the highest average backward fixation times occurred in Sentence Type III. Results taken from Figures 9 and 11 concerning what may be taken as the disruptive nature of a prepositional phrase inserted between the verb and object parallel what many researchers have found concerning the relationship between difficulty of material and eye movements; that is, as material becomes increasingly difficult, more and longer forward and backward fixations occur (Tinker, 1951).

Significant differences were found between average duration of forward and backward fixations (Figure 8). The relative contributions of linguistically-defined areas to this effect are shown by Figure 10. Subjects had the shortest average fixation time after they regressed back to the area of the object, compared to all other areas. When the averages of three kinds of fixations for every area of the experimental sentences were compared, no significant differences were found (Figure 13). These two results (Figures 10 and 13) show that subjects in the present experiment had different average backward fixation times which were related to the linguistically-defined areas. Relative to the Exploratory Hypothesis, which was an attempt to isolate the point at which a subject made a "decision" to visually regress, this interpretation suggests that this decision may be related to the kinds of linguistic constraints which are part of the area to which the subject regresses. Since in this experiment no test was made for this suggestion, no probability statement can be made.

2) <u>Frequency of fixations used as the dependent variable</u>. When

the linguistically-defined areas of the experimental sentences were analyzed using the number of times an area was fixated as the dependent measure, only one significant difference emerged: subjects fixated in a forward direction a greater number of times per linguistic area ($p < .001$) than they did in a backward direction. This result is what would be expected and confirms many of the experiments which show that mature readers make more forward fixations than regressive, or backward, fixations (see Figure 6).

Taylor (1966) has obtained normative data on the average number of words per fixation. For subjects reading between 250 and 350 words per minute, the number of words per fixation ranges from 1.1 to 1.3; that is, subjects reading between 250 and 350 words per minute are "looking at" just about every word.

Only subjects who read between 250 and 350 words per minute were used in the present experiment. A possible interpretation of the absence of any significant relationship between number of fixations and linguistic area may involve the consistency of fixations across linguistically-defined areas; that is, subjects in this experiment looked at almost every word. Indeed, support for this interpretation can be seen in Figure 6, which shows that the average number of forward fixations for the subject, verb and object was 1.30.

3) Total fixation time used as a data check. Total fixation time (i.e., the total amount of time a subject spent in "looking at" a particular area in the experimental sentence) is a function of the number of times a subject fixated the particular area and the length of fixations to the particular area.

The analysis of total time parallels the analysis of average fixation time and frequency of fixation time (see Figures 14, 15, 16 and 17). When the number of fixations for a given linguistically-defined area is multiplied by the average fixation time for that area, the result is total time spent on a particular area. The analysis of total time did predict the result of this computation and thus served as a data check. However, the analysis of total time yielded one result which did not appear in the analysis of either average fixation time or frequency of fixation: a three-way interaction of linguistic area by position of prepositional phrase by fixation direction. The results of this three-way interaction (see Figure 18) are a reflection of the interaction effects of the analysis of average fixation time and frequency of fixation.

Limitations and Assumptions

Because subjects were not selected at random from a larger population of mature readers, the results of this study cannot be generalized to all mature readers. Results of this study can be applied only to the ten subjects selected at the University of Massachusetts.

The results of this study cannot be generalized to sentence types other than the active sentences used in the experiment, since the active sentences used here were not randomly selected from the larger population of active sentences.

The results of this study cannot be generalized to "normal" reading situations, since subjects used in the experiment were required to read, one at a time, single-line sentences which started in the same physical location on a visual projection screen under controlled conditions.

Instrumentation and scoring method contribute error to the measurement of eye movement. The Eye-Trac measuring instrument has been estimated by the Biometrics Company to allow less than one percent error. It is assumed that errors in hand-scoring the eye movement records are randomly distributed across all experimental sentences and across all subjects.

It was assumed that the way in which subjects read the experimental sentences was similar to the way they would have read other active sentences under non-controlled conditions.

A limitation of the present study concerns the eye fixation recording. Only the fixations occurring on the linguistically-defined words were recorded. Thus it was possible for subjects to notice in peripheral vision other words which were not counted as being fixated. In some cases, these other words were levels of the independent variable. For example: if in the sentence "The lazy student failed the hard exam" an eye fixation was recorded as occurring on the word "student," the word "failed," which was another level of the independent variable, could have been noticed in peripheral vision but would not have been recorded.

An additional limitation concerns the adequacy of the post-test. Subjects were told to attend to the meaning of the sentences and that they would receive a word recognition test. This instruction may have influenced subjects to "attend" only to the words and not the meaning.

Furthermore, in places where the analysis of data showed no differences (i.e., frequency of fixation between subject, verb, and object of the verb) the no-difference result might in part be due to the subjects not reading for comprehension. The above point should be considered in light of the pre-test, which showed that all subjects normally read at a rate of between 250 and 350 words per minute; reading at this rate probably involves eye movements that are well learned and consistent across tasks.

A major methodological problem concerns the fact that subjects did not look at every level of the independent variable in the experimental sentences. Since there was no one-to-one correspondence between the moment at which the independent variable was presented and the moment at which the subject looked at it, the term "average fixation time" by definition in the study means the average fixation time only when the subject was looking at the levels of the independent variable.

Theoretical and Practical Considerations

Both Goodman (1970) and Gibson (1966) describe the reading process in terms of accessing and processing information. Gibson characterizes reading as the search for information. The notion that not all the text is processed by the proficient reader is demonstrated by the occurrence of proofreaders' errors and by Kolers' (1970) experiment concluding that when the proficient reader is forced to adopt a letter-by-letter strategy there is a drastic reduction in his reading speed.

The notion that an organism will actively select "important" information from a visual stimulus has been demonstrated by Skinner (1972). Skinner reports an experiment in which pigeons were trained to select visual information. First a pigeon was trained on either a form or color discrimination problem; that is, the bird was consistently rewarded for pecking a particular form or a particular color. Second, the forms or colors were gradually faded out so that the pigeon could not respond consistently to the appropriate stimulus. Third, another response key which controlled the clarity of the stimuli was made available to the bird. After a short time the pigeon responded by pecking the new key which controlled the clarity of the original stimuli. The pigeon then responded to the appropriate stimulus. Skinner therefore demonstrates that a pigeon can be trained to be selective in terms of relevant information.

Levin (1967) holds the opinion that in reading there is an active processing of some information, while other information is processed only partially. Support for Levin's opinion was given by Mackworth and Morandi (1967), who showed, using a pictorial display, a difference in the amount of information processed.

Wanat (1970) posed the following question:

> "Would this same selectivity about what is fixated occur in the allocation of visual attention when the perceiver is examining a linguistic instead of a pictorial display? Marchbanks and Levin (1965) have shown that certain areas of the word are more informative to the reader than others. Brown and McNeill's (1966) study of the tip of the tongue phenomenon in recalling words seems to indicate the same thing. Although neither the Marchbanks and Levin nor the Brown and McNeill studies dealt with overt scanning behaviors in reading, their findings show that there are differences in the informativeness of areas of words. These findings (Marchbanks and Levin; Brown and McNeill), plus evidence that the text is sampled in reading (Hochberg, 1970; Kolers, 1970), and evidence that visual attention is selectively allocated in the scanning of pictorial displays (Mackworth and Morandi, 1967) led to the hypothesis that the reader selectively allocates his visual attention to

> different areas of the printed text. Specifically, it was hypothesized that there would be significant differences between the amounts of visual attention the reader would allocate to different areas of the sentence."

Wanat confirmed his hypothesis with regard to the selectivity of visual "attention."

The Greenberg (1970) study cited earlier showed that word category (e.g. noun, verb) is a grammatical feature which helps to determine the amount of processing allocated to different parts of the text. The Greenberg study demonstrated the importance of the verb. Gladney and Kralee (1967) also found that tampering with the verb affects "processing." As cited in the review of the literature in Chapter I, the importance of the sentence verb was also indicated by Fodor, Garrett and Bever's (1968) finding that the nature of the complement structure of the verb affects the ease of processing.

Interpretation of the data from the present experiment generally supports the hypothesis that visual scanning behavior is not random and that specific indices of eye movement reflect linguistic constraints of our language. Since the present study was not designed to measure processing time, interpretation of the data from the present experiment does not directly support the hypothesis that visual scanning behavior or "looking time" is analog to processing time. However, the present finding that subjects look back at the verb an average of 40 milliseconds longer than at the object (see Figure 10) may be taken to suggest that fixation time under certain linguistic conditions may be analog to processing time. Earlier Hochberg (1970) was quoted as describing the reading process as a kind of guessing game in which the reader formulates guesses about the reading material and then fixates those parts of the text that will enable him to formulate new guesses as well as to check his current guesses. In the present study, the relative importance of the object in terms of average fixation time (Figure 11) may suggest, using Hochberg's theoretical notion, that when subjects' guesses are wrong (as may be the case with Sentence Type III, where the object of the verb does not follow the verb but is interrupted by a prepositional phrase) they need time (as reflected by higher average fixation time for the object; see Figure 11) to formulate new guesses and to check them. Goodman (1970) offers this idea:

> "Reading is a selective process; it includes partial use of available minimal language cues selected from perceptual input on the basis of the reader's expectation. As this partial information is processed, tentative decisions are made to be confirmed, rejected, or refined as reading progresses."

More simply stated, Goodman theorizes that reading is a psycholinguistic guessing game involving an interaction between thought and language. He further states that efficient reading does not result from precise perception and identification of all elements, but from skill in selecting the fewest and most productive cues necessary to produce guesses which are right the first time. Indeed, when the linguistic constraints are arranged so that the reader's expectations are correct (assuming that in active sentences such as those used in this study, the reader expects the object of the verb to immediately follow the verb), the relative importance of the object in terms of average fixation time (Figure 11) becomes subordinate to the importance of the verb. In other words, in terms of the psycholinguistic guessing theory, the readers in this experiment when guessing correctly (in Sentence Type I--e.g., "In the store the new pants fit the man," and Sentence Type IV--e.g., "The new pants fit the man in the store"), using information supplied by the verb (highest average fixation time for Sentence Types I and IV), had to look only briefly (relative to the verb) at the object in order to check their guesses. The implication of this explanation is that the ability of the reader to anticipate that which has not been seen is vital in reading.

Gaarder (1970) argues that eye movements mediate the input of visual information. Simply stated, his argument is that the input of visual information is discontinuous (packaged, sampled, gaited, intermittent, etc.) with the discontinuity mediated by "jumping" eye movements. Gaarder offers the following evidence to support his claim:

> "1. The oldest experimental evidence is the phenomenon of flicker fusion, from which it can be argued that, if, at some particular flicker rate, flicker is not perceived, these chunks of intermittently presented information are subjectively smoothed in the same way as the chunks mediated by eye movements.
>
> "2. Conversely, if there were a means to artificially prevent packaging of visual input, it could be predicted that perception would cease, as happens when eye jumps are automatically canceled in stopped-retinal-image experiments.
>
> "3. Another argument holds that, if perceptula input is intermittent, there must be inhibition of vision during the periods when input is not being processed, i.e., during eye jumps. This is found to be the case during jumps: visual thresholds are raised and inhibitory neurons are activated in the lateral geniculate nucleus.
>
> "4. Another line of reasoning holds that, if eye jumps establish packages of information, they should be followed by cortical activity marking the arrival of the packages. This is indeed the case: the eye jump triggers occipital activity, recorded as a typical averaged response. That the eye jumps are correlated with alpha rhythm is also relevant here, because it shows a relationship between packaging due to eye jumps and more general cortical packaging processes.

> "5. Less-direct evidence that eye jumps establish discontinuity is provided by the finding of changed fixation eye-jump vectors as a result of changes in visual stimulus. Here, the argument is that, if the form of visual input is controlled by a feedback output of the visual system, changing the stimulus would change the output that controls the input."

Assuming Gaarder's (1970) argument correct and applying the data from the present research, the suggestion is that eye movements mediate the input of visual information and that studies of mean fixation times as they relate to written language constraints may be a method of estimating processing time.

Assuming that Eye-Trac recordings of average backward fixation time are analog to actual average backward fixation time, and considering average backward fixation times for the verb and object (Figure 10), the following statement can be made: relative to the theoretical psycholinguistic strategy suggested by Goodman (1970) and Hochberg (1971), subjects in the present experiment took an average of 60 milliseconds longer to re-check (look back at) expectancies concerning the verb compared to the object. Moreover, the recording of the highest average backward fixation time for the verb may indicate the relative importance of the verb in developing expectancies. The interpretation given in the preceding sentence gains further support from the studies cited in the review of the literature in Chapter I, concerning the importance of the verb for efficient processing (Gladney & Kralee, 1967; Fodor, Garrett & Bever, 1968).

The general support that the present study gives to the notion of visual selectivity leads to implications for training efficient visual search strategies. If additional research shows that the results of this experiment can be generalized to different readers, then further experimental procedures can be developed in which tests will be made to determine if beginning readers can be instructed to visually attend to "important" areas in the sentence. The further discoveries of relationships between visual scanning behavior and the constraints of written language could be one way in which reading teachers might identify and then emphasize the importance of linguistic segments in the teaching of reading.

Conclusions

The major conclusion of this study, based on the results discussed above, generally supports the notion that when using average fixation time as a dependent measure the subjects in the present experiment were visually selective. Moreover, this selectivity was related to both linguistically-defined areas and location of interruption of the experimental sentences by the insertion of a prepositional phrase.

However, this conclusion regarding visual selectivity was an extension of the major hypotheses and not a direct result of confirmation of those hypotheses. The reason for this lies in the wording of the major hypotheses. The results indicate that the major hypotheses were oversimplified; the phenomena observed were more complex than was hypothesized. Results of this study suggest that visual selectivity in reading is complex and involves an interaction between linguistic structure and expectations of the subject with regard to linguistic structure. It should be emphasized that the phenomena being observed are complicated and that the Wanat (1970) study and the present study have been pioneering attempts at understanding the relationship between visual behavior and the reading of simple sentences.

Another conclusion of the present study is that currently available methodological approaches to the study of this kind of phenomena are inadequate.

Future Research

Both this study and the Wanat (1970) study have implications for further research. Wanat found that subjects were visually selective when they read different types of sentences. This study has shown that selected subjects are visually selective (i.e., they have different average fixation durations for different experimental sentence areas) when reading only one sentence type (i.e., an active sentence).

The following research proposals are suggested by the present study:

1) Experiments designed to test for differences in average fixation durations in sentence types other than the active sentences used in the present study.

2) Experiments designed to generalize the results of the present study to a larger population of readers.

3) Experiments designed to predict total "looking" time for different sentence types, using average fixation duration as the dependent measure.

4) Experiments designed to investigate average fixation duration for linguistic areas within different sentence types at different levels of reading ability across different age groups.

5) Experiments designed to investigate other aspects of linguistic structure, such as the effects of prepositional phrase placement.

6) Experiments designed so that subjects are reading under more "normal" conditions; for example, subjects' eye movements could be analyzed while they were reading a paragraph, rather than single sentences presented one at a time.

7) Experiments designed to study the complex interactions which were uncovered in the present study (see "Limitations and Assumptions").

8) Experiments making use of real time computer analysis of eye movement recordings.

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