Fall 1987

THE LATERALIZATION OF THE WORD FREQUENCY EFFECT

DAVID ALAN BOZAK
University of New Hampshire, Durham

Order Number 8800184

The lateralization of the word frequency effect

Bozak, David Alan, Ph.D.

University of New Hampshire, 1987

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

PLEASE NOTE:

In all cases this material has been filmed in the best possible way from the available copy. Problems encountered with this document have been identified here with a check mark __✓__.

1. Glossy photographs or pages _____
2. Colored illustrations, paper or print ______
3. Photographs with dark background _____
4. Illustrations are poor copy ______
5. Pages with black marks, not original copy _____
6. Print shows through as there is text on both sides of page ______
7. Indistinct, broken or small print on several pages __✓__
8. Print exceeds margin requirements _____
9. Tightly bound copy with print lost in spine ______
10. Computer printout pages with indistinct print ______
11. Page(s) __________ lacking when material received, and not available from school or author.
12. Page(s) __________ seem to be missing in numbering only as text follows.
13. Two pages numbered ______. Text follows.
14. Curling and wrinkled pages _____
15. Dissertation contains pages with print at a slant, filmed as received ________
16. Other ____

UMI

THE LATERALIZATION OF THE WORD FREQUENCY EFFECT

BY

DAVID ALAN BOZAK
BA, Rice University, 1976
MA, University of New Hampshire, 1978

DISSERTATION

Submitted to the University of New Hampshire
in Partial Fulfillment of
the Requirements for the Degree of

Doctor of Philosophy

in

Psychology

September, 1987

This dissertation has been examined and approved.

Dissertation director, Dr. John Limber
Associate Professor

Dr. Grant Cioffi, Associate Professor

Dr. Albrecht Inhoff, Assistant Professor

Dr. William Stine, Assistant Professor

Dr. James Weiner, Associate Professor

8/5/87
Date

ACKNOWLEDGEMENTS

Dr. John Limber has been a most generous and patient advisor. He has been generous with his time, his insight and his wit. He has been patient as I struggled with numerous hurdles, always encouraging. I enjoyed working for and with him over these years. I could not have been more fortunate.

Dr. Grant Cioffi enthusiastically aided me early in this endeavor and provided support and encouragement when I brought this task to a closure. Dr. James Weiner has also been patient and encouraging, both in this project and others. I am very appreciative of the efforts of Dr. William Stine and Dr. Albrecht Inhoff. They gracefully filled open positions on my committee and contributed to this final product.

Many of my friends, parents (both sets), and colleagues at SUNY College at Oswego have kept after me, telling me to finish! Their moral support and at times technical support have been very welcome.

And finally, I cannot begin to repay my wife, Esther, for the many hours she has put into this project. Her aid as a statistician and devil's advocate was needed. Her patience while babysitting computer analyses was endless. Her love and support were above and beyond the call of duty. I truely could not have endured this without her.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

THE LATERALIZATION OF THE WORD FREQUENCY EFFECT

by

David Alan Bozak
University of New Hampshire, September, 1987

Two lexical decision experiments were performed to investigate the lateralization of the word frequency effect and the interaction with word class. Positive results would support proposals of multiple lexicons in lexical retrieval models. The first was a small-n experiment varying visual angle of presentation, signal to noise ratios, visual field and word class (noun/verb) while using high frequency word and nonword items. The purpose of this experiment was to document the sensitivity of observers to material presented varying distances from a central fixation point while replicating previous research results of a word class by visual field interaction. The second experiment was a large-n design varying visual field, word class (noun/verb/mixed), and word frequency, looking for greater differences in lateralization of word class by frequency. Results of the first experiment show no visual field by word class interaction, failing to replicate previous research. Speed of response slowed linearly with increasing visual angle of presentation for both visual fields, despite moving away from a region of macular overlap to parafoveal presentation. In experiment two, a strong frequency effect was found,

along with an interaction with word class and visual field. This interaction, however, was due to aberrant performance for medium frequency nouns. Considered along with the inconclusive literature on lateral effects of word class and word frequency, and recent failures to replicate Bradley's (1978) model of open- and closed-class lexicons, the research focus must shift toward a closer examination of the relationship between two areas: (1) the method of generation of a lexical access code (which may or may not involve the RH) and, (2) the relationship between a rapidly calculated direct access code and an ordered lexicon.

CHAPTER I

INTRODUCTION

The word frequency effect is, briefly, that more common words in our language are recognized more quickly and with less error than less common words. This is an old and robust effect, found in many paradigms, including naming, lexical decision, and reading tasks, and in both visual and auditory modalities.

Among the earliest examinations, Solomon and Postman (1952) found that visual recognition thresholds for words were negatively correlated with the frequency of exposure to a given word. Oldfield and Wingfield (1964, 1965) examined the time needed to name a simple outline drawing and found a negative linear relationship between naming latency and log frequency.

Rosenzweig and Postman (1958) summarized the findings of a number of studies and found three major factors that influence intelligibility in both English and French. Among these were that the greater the relative frequency of usage of a word in a language, the more intelligible that word would be. This was true for both auditory experiments and visual experiments. In auditory tasks, intelligibility was measured by the intensity of noise needed to mask a word, while in visual tasks intelligibility was measured by the duration of exposure during a tachistoscopic presentation of a word.

Length was also a factor, but one which interacted with modality and word frequency. Auditorily, the greater the length, the greater the degree of intelligibility, when frequency was held constant. Visually, length was not a significant factor for high frequency words and exerted a negative effect on low frequency words.

Stanners, Jastrzembski, and Westbrook (1975) examined the effects of frequency and visual quality in a word-nonword classification task. Frequency produced large effects for word and nonword detection, with the size of the nonword frequency effect (nonwords had been derived from words) half the size of the word frequency effect. Frequency did not interact with quality of presentation, but the effect was present in both non-degraded and degraded presentations.

In a more recent word recognition paradigm, the effects of five lexical variables on performance was investigated by Balota and Chumbley (1984). Their most important finding was that word frequency was highly related to lexical decision performance beyond its joint relationship with other variables (instance dominance, category dominance, word length in letters and word length in syllables), but found little evidence of the effect in a category verification performance task. They argue that word frequency is an important structural variable available to a subject, but that the effect of frequency is evident only under tasks, such as lexical decision, that places a premium on such information with little postaccess processing. In category verification, word frequency might affect the lexical access time, in order to determine other information about the target item, but plays little role in the comparison task itself.

Three major conclusions based on recall (rather than recognition) paradigms were reported by Foos, Lero, McDonnell, and Sabol (1985). They found that frequency measures for recalled words were significantly correlated with an objective count (Kucera and Francis, 1967). Secondly, the performance of subjects on differing tasks supported the notion of a frequency ordered lexicon rather than a randomly ordered lexicon (cf. Landauer, 1975), answering a criticism of Balota and Chumbley (1984) of lexical decision tasks testing such a hypothesis. Thirdly, word frequency and number of meanings exerted independent influences on performance, supporting Whaley (1978) who found that word frequency, word length and 'richness of meaning' were the three major independent factors in a lexical decision task.

Lorch (1986) also found a word frequency effect using a word reading task as opposed to the more traditional lexical decision or naming tasks. Reading times decreased as frequency increased and length decreased, with frequency showing greater effect for longer words.

Such research clearly shows that the word frequency effect exists as a major variable in lexical access. Two major theories of word recognition, both relatively old, were developed from the existence of the word frequency effect (Morton, 1969, 1970, 1982; and Forster, 1976, 1979). While the earlier mentioned studies offer quantitative data with which to evaluate any model of lexical retrieval, we will see that both Morton's and Forster's models inadequately handle quantitative word frequency data.

Morton describes what he calls a Logogen Model of word recognition. Each word in our internal lexicon is represented by three logogens associated with auditory input, visual input, and output. The internal lexicon is a system comprised of these three logogens, and associated buffers, analysis processes and conversion processes, tied into a cognitive system.

A logogen is a device that counts the number of features or attributes described by multiple analyses of an original stimulus that are matches for its own defining features and attributes. When this count exceeds some threshold, a match between the stimulus item and the logogen is declared, and the word represented by the logogen is retrieved as the "recognition" of the item.

The threshold for all logogens are not identical, nor are they unalterable. The threshold or "critical value" is based on the number of features associated with a logogen in order for a match to be made. Identification of a logogen temporarily reduces the critical value. The return of this critical value to its original resting state is slow and recovery is incomplete. The more frequently a logogen exceeds threshold, the lower the resting state becomes for that logogen.

In the original model (1969, 1970), the locus of the word frequency effect is clear. Mere exposure to words over time has caused gradual but certain changes in the resting states of the associated logogens. The more exposure to a word, the closer the resting state for the logogen to threshold, and thus the fewer features necessary for future recognition of that item. In general, given some rate of feature extraction, more common words will be recognized more quickly, or, said another way, fewer features will need be matched for a decision in favor of a high frequency item for recognition.

Swift (1977) incisively describes the shortcomings of this model. The most pertinent objection, for the purposes of this discussion, is the fact that Morton's Logogen Model yields no quantitative predictions, nor does it offer a mechanism to yield different predictions for different methods of accessing the internal lexicon.

Changes to the Logogen Model, such as Becker's verification model (1973) or Swift's Spaghetti Model (1977), modify various attributes of the model, but not the basic mechanism for describing the effect of word frequency. Words are ordered by frequency and are either searched serially (Becker) or reach threshold at different times in a fashion linearly related to frequency (Morton, Swift).

In Morton's revised model (1982), the word frequency mechanism is removed from the logogen system as such. The logogen system is now a purely passive, non-attention demanding, content-addressable recognition system. The word frequency effect is attributed to the (unspecified) structure of both semantic and associative components of the cognitive system, the main beneficiary of the output of logogens. Further, the word frequency effect is an index of some other property (again unspecified) rather than being directly represented.

Forster (1976) provides another mechanism to account for the word frequency effect in word recognition. He combines, in a sense, the serial processing of Becker with a localized search, constrained by certain orthographic features or visual properties of an item. The internal lexicon for Forster is organized first by specific orthographic features and within these subsets (or <u>bins</u>) by frequency. The extraction of certain features of a stimulus item constrains the search area of the lexicon, which is then serially searched, based on frequency.

Again though, Forster's model offers no exact quantitative predictions, and offers only vague suggestions of the critical features defining bins in memory. While estimates of the effects of various bin sizes on retrieval rates can be made, these are constrained by definitions of bin descriptions and bin sizes and are not necessarily a result of the structure of the model. Thus, ballpark estimates are generated by this model, under constraints not necessarily mandated by the description of the model.

One reason for the inability of these models to offer more precise estimates of the effects of frequency is that little is known about the origin (both cause and development) of the word frequency effect. Some evidence suggests that age of acquisition of a word is highly correlated to the frequency of the word in the adult lexicon. Carroll and White (1973), following the work of Oldfield and Wingfield (1964, 1965), used a picture naming task to examine the effects of several variables on naming latencies. While they found their data to be in relatively close accord with Oldfield and Wingfield, the inclusion of age of acquisition estimates in the multiple regression analysis led to the conclusion that only the age of acquisition variables contained significant information necessary to predict the dependent variable.

In examining the ability of young adults to produce instances of category membership, Loftus and Suppes (1972) found that mean response latencies were best predicted by a combination of three structural variables: dominance in the category, frequency of the category in childrens's vocabulary, and frequency of the most likely response in children's vocabulary.

Worden and Sherman-Brown (1983) compared young versus elderly memory for words and found that the frequency of usage of a word during an individual's younger years was the best predictor of recall. Cirrin (1984) found that the best predictor of lexical decision was the Kucera and Francis (1967) word frequency count for adults and the Kolson (1961) juvenile frequency counts for children, with age of acquisition also a significant contributor in explaining the variance in decision latency.

While these studies were not specifically seeking the origin of the word frequency effect, they do suggest a possible explanation of the effect. Words to which we are exposed early or often, build up a strengthened trace in memory to that item. Alternatively, it might be that there are many instances of the item distributed in our memory in a random fashion thus allowing rapid access to a more common or frequent item. (Landauer, 1975; though see Foos, Lero, McDonnell, and Sabol, 1985). Either a structured or unstructured lexicon could incorporate the word frequency effect as being related to the number of occurrences to the word in our past.

While this is an intuitively pleasing explanation of the effect, it is not a complete one. A study by Marshall and Holmes (1974), in a naming task, found that the word frequency effect was, first of all, localized to a single hemisphere, and secondly that the effect was localized to the hemisphere opposite to the hemisphere responsible for language processing in the normal adult human. Specifically, using a tachistoscopic task and an identification response, Marshall and Holmes found a noun facilitation effect in the left hemisphere (concrete nouns perceived at lower threshold than other parts of speech) and that the right hemisphere was the primary mediator of the word frequency effect.

This is a significant finding. Mere exposure in itself cannot explain why the word frequency effect should be localized at all, and certainly not why the effect should interact with word class.

One particular form of word retrieval would benefit from such a partitioning. Bradley (1978) suggested that sentence processing would benefit by separating the lexicon into multiple lexicons, a closed class vocabulary and an open class vocabulary. Open class vocabulary items would be those elements of the major lexical categories (nouns, verbs, adjectives). Closed class vocabulary items would be those elements of the minor lexical categories (determiners, auxiliaries, prepositions, and so on). If multiple lexicons do exist, whether in the form suggested by Bradley or in some other form, then parallel processing forms of word retrieval would be plausible. If differential processing of words exists between the two hemispheres, then supporting evidence for multiple lexicons would also exist.

Owing to concerns over the methodology used by Marshall and Holmes, Bozak (1978) sought to clarify the issues raised by their study. Using a naming task, he found support for the notion that the word frequency was not diffuse, but localized, and extended the Marshall and Holmes findings in certain ways. The finding of a localized word frequency effect was supported, but the localization interacted with word class. Specifically, the right hemisphere showed a word frequency effect for nouns, but not for verbs, and the left hemisphere showed a word frequency effect for verbs, but not for nouns.

This finding of support using a different paradigm is important enough to be given further consideration. Part of the concern over these findings stems from the extreme difficulty encountered in gathering data. Common paradigms adopted from the literature were not found to be as reliable as reported. Bozak (1978) describes the difficulties encountered.

The present studies were designed to examine this possible differentiated word frequency effect using a lexical decision task. Two approaches are taken. The primary purposes of the first experiment are to document the sensitivity of observers to material presented varying distances from a central fixation point and the processing times necessary to make lexical decisions based on the presentation of material to either hemisphere. This will be accomplished using a single subject design, varying visual field of presentation, word class, visual angle and word:nonword ratios.

Visual angle of presentation is an important factor. An assumption in laterality studies is that differences in performance on a task is a function of callosal transmission. Material must be presented, then, so that the initial input is made solely to one hemisphere or the other. It is commonly believed that in order to provide input to the left hemisphere, for example, material should be presented tachistoscopically to the right of fixation, which projects to the nasal hemiretina of the right eye and the temporal hemiretina of the left eye. This would result in information following the visual pathway to the left hemisphere. The converse would be true for presentation to the right hemisphere. However, this description is overly simplified. To begin with, there is a small central strip around the vertical meridian, approximately 1 degree wide, where receptive fields project both ipsilaterally and contralaterally. The projections of X-, Y-, and W-cells around this strip vary to differing degrees. Ipsilateral projections primarily originate in the temporal hemiretina. Contralateral projections primarily originate in the nasal hemiretina, but may also be located temporally. Lennie (1980) provides a thorough review of visual pathways. Varying the visual angle of presentation will allow for an examination of the effects of these differing patterns of projection.

The second experiment will be primarily a between-subjects version of experiment one. Given a fixed visual offset, material will be presented which is more varied with regard to word class and frequency.

CHAPTER II

EXPERIMENT 1: SINGLE SUBJECT APPROACH

Methods

Subjects. There were two subjects in the first experiment. One subject was this author, the other an undergraduate who was paid for his participation. The subjects were strongly right-handed and male.

Apparatus. The display of material for this experiment was controlled by a microcomputer-driven graphics system. The microcomputer was a North Star Horizon II running a CP/M 2.2 operating system. The software controlling the display was written in FORTRAN and Z80 assembler. The graphics subsystem was a MicroAngelo graphics board, made by Scion Corporation, capable of a resolution of 512 (horizontal) and 480 (vertical) pixels. The display device was a 15 inch (38.1 cm) Ball Corporation monitor (RD150, with a 22 Mhz bandwidth), with a P4 phosphor (black and white, with a 60 microsecond persistence). The keyboard used as an input device was a selectric-style keyboard made by Keytronic Corporation. See Appendix A for controlling software. Subjects sat in a chair with their head in a chin and forehead rest, 18 inches (45.72 cm) from the center of the display.

Procedure. Each subject viewed material described by a completely crossed, four factor design. The four independent variables and their levels were:

1) visual field (left, right)
2) visual angle (0.75, 1.75, 2.75 degrees from fixation)
3) signal to noise ratio (90:10, 70:30, 50:50, where signal is word item and noise is nonword item)
4) word class (noun, verb)

This is a 2 X 3 X 3 X 2 design for a total of 36 conditions. A single trial in any cell consisted of the following events:

1) blank screen with a "+" at fixation (1 second duration)
2) countdown display of the digits 3, 2, 1 displayed at fixation (2 second duration)
3) simultaneous display of "+" at fixation and the stimulus item (variable duration)
4) blank screen while waiting for the subject's manual response (variable duration)
5) display of feedback concerning the response (1.5 seconds)

The stimuli were vertically arrayed words and nonwords. The items were 5 letters in length and of high frequency (21 or more occurrences per million based on the Kucera and Francis word corpus (1967). The nonword items were formed by changing one letter of each word to form a pronounceable nonword item. Changes in letter position were balanced, with all positions being changed equally often.

There were 50 nouns, 50 verbs, 45 nonword nouns and 45 nonword verbs. No item appeared more than once in any block of 100 trials. The nonword items for each word class were randomly divided into three groups of 15 items each. One group of 15 items appeared solely in the Left Visual Field (and projecting to the right hemisphere, thus LVF-RH). Another group of 15 items appeared only in the Right Visual Field (RVF-LH). The remaining items were randomly presented in either the LVF-RH or RVF-LH. This would allow a comparison of rates of learning of the nonwords in either hemisphere (Rabin and Zecker, 1982).

A block of 100 consecutive trials consisted of a fixed visual angle and a fixed signal to noise ratio with items varying in visual field of presentation and word class. For each of the 36 cells determined by the above factors (2 X 3 X 3 X 2) there were 300 trials, for a total of 10,800 word/nonword decisions. This was broken into 12 sessions of nine blocks of 100 trials with two minute rest periods between blocks, with rest periods of five minutes between blocks three and four and blocks six and seven. Before each session, a practice block of 100 items was presented to re-familiarize the subject with the procedure. The practice block was composed of material similar to that used in the experimental conditions. The method of ascending and descending limits was used during the practice session to change the exposure duration of the items to maintain a constant level of difficulty. Practice began at 175 millisecond exposure and changed in increments of 5 milliseconds. The rate of presentation of the experimental material was the average of the rates of the last 25 trials of the practice block, approximately five to eight milliseconds.

Due to the limitations of the video refresh circuitry, when presentations are less than 33 milliseconds, not every row of pixels which make up individual characters of the word are displayed. This has the effect of making the task even more difficult, as the actual resolution of the word is reduced. If the presentation is less than 16 milliseconds, the hardware will in fact present the material for 16 milliseconds.

For each item, a manual response (key press) to indicate word/nonword was made by the subject's preferred hand. Subjects were instructed to respond as rapidly and as accurately as possible. The response and the latency to respond were recorded.

Results

Two right-handed male subjects participated in experiment 1, viewing a total of 10,800 trials (subject one) and 9511 trials (subject two). Subject two did not complete the experiment, but as the blocks were randomly ordered, had completed enough trials to provide sufficient data for all conditions. Of these trials, 6 (subject one) and 47 (subject two) were considered missing data because of extremely short reaction times (RT), probably the result of keyboard bounce problems. All reaction times over 150 milliseconds and under 4 seconds were kept.

The data can be analyzed in a variety of ways. As this experiment was primarily descriptive in design, the performance of the two subjects will be described in two ways. First, reaction times will be inverted and multipled by 1000, yielding a new variable called speed, which is expressed in seconds, rather than milliseconds. This will effectively remove the masking effects of the extreme skew of the data. A variety of plots comparing speeds of each subject under all levels of the four factors in this experiment are examined.

Secondly, the learning curves of both the words and the nonword items are examined. Both raw reaction times and smoothed adjusted reaction time plots are considered. Of particular interest are the hemispheric differences that emerge.

Measurements of Speed for Both Subjects

Speed is defined as inverted reaction time multiplied by 1000. Figures 1 through 6 show boxplots of speed measurements for both subjects, broken down by either visual angle or signal to noise (S:N) ratios. Two characteristics of the curves are immediately apparent. First, subject two is consistently slower than subject one. Second, subject two is much more variable in his responses, with many more outliers.

In the first three figures, there is a consistent loss of speed with increasing visual angle. Subject two shows a

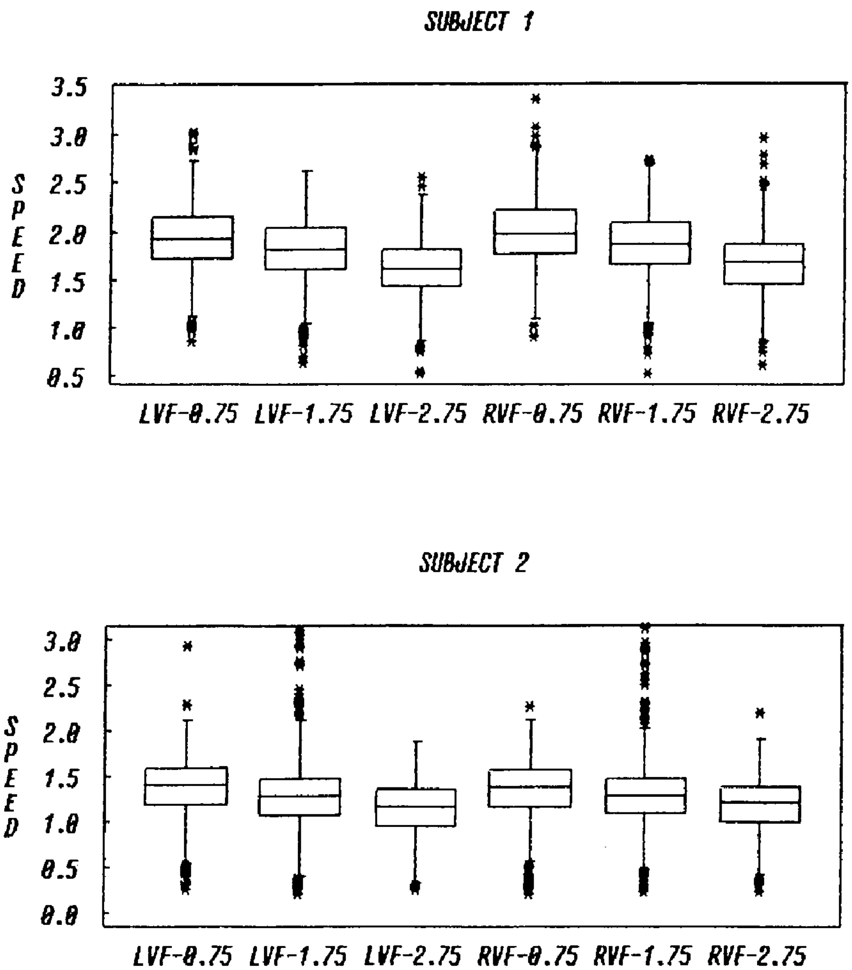


Figure 1. Speed versus Visual Field by Visual Angle

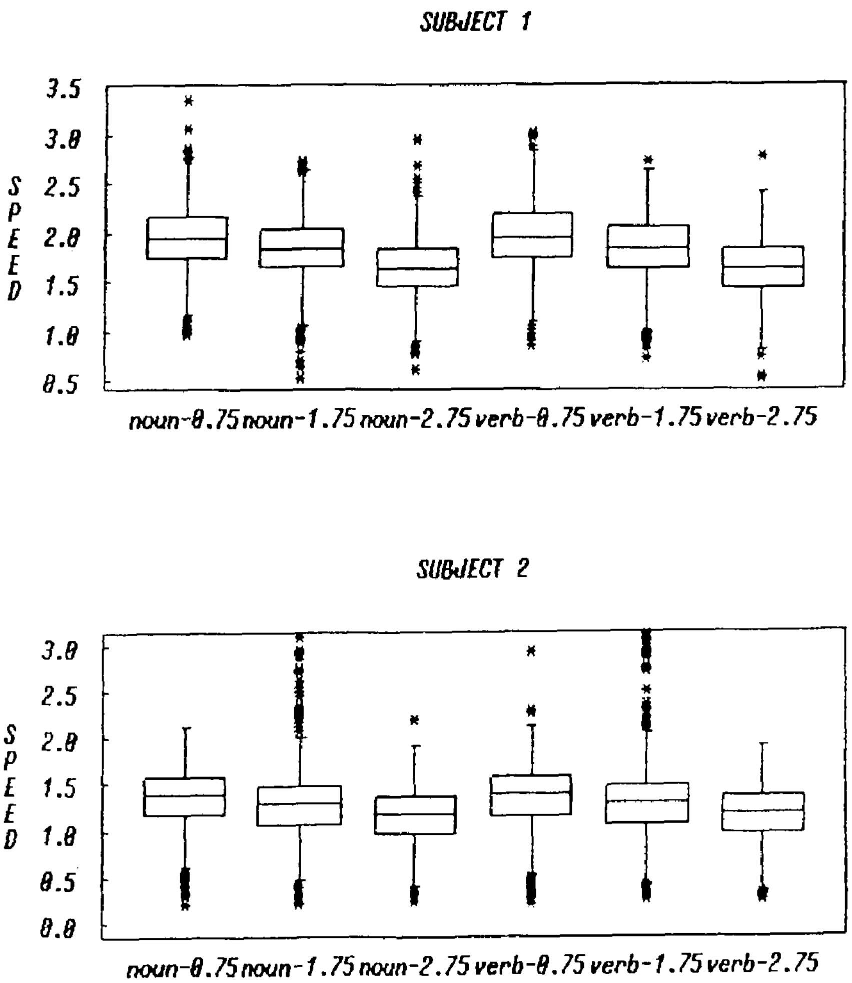
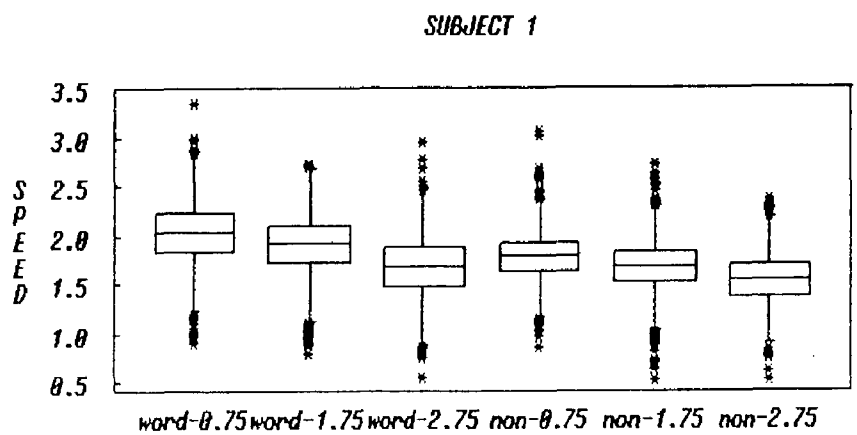


Figure 2. Speed versus Word Class by Visual Angle



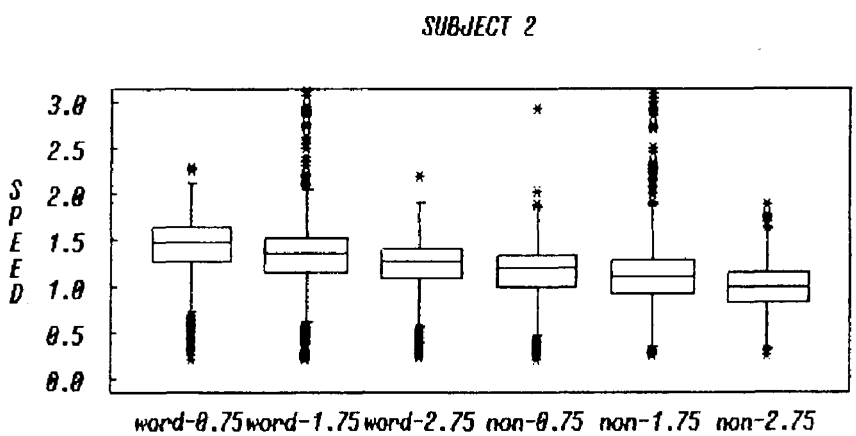
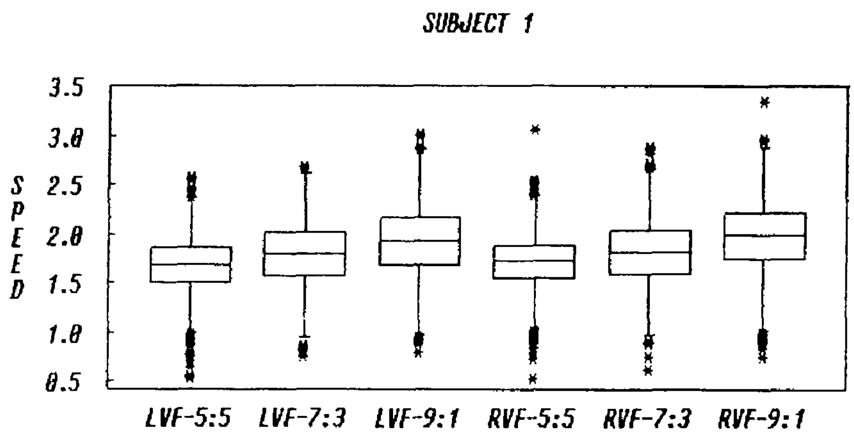


Figure 3. Speed versus Word/Nonword by Visual Angle



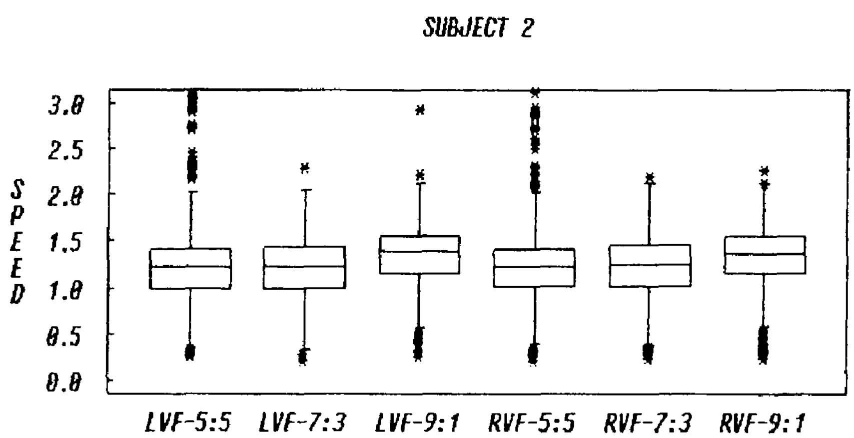


Figure 4. Speed versus Visual Field by Signal:Noise Ratio

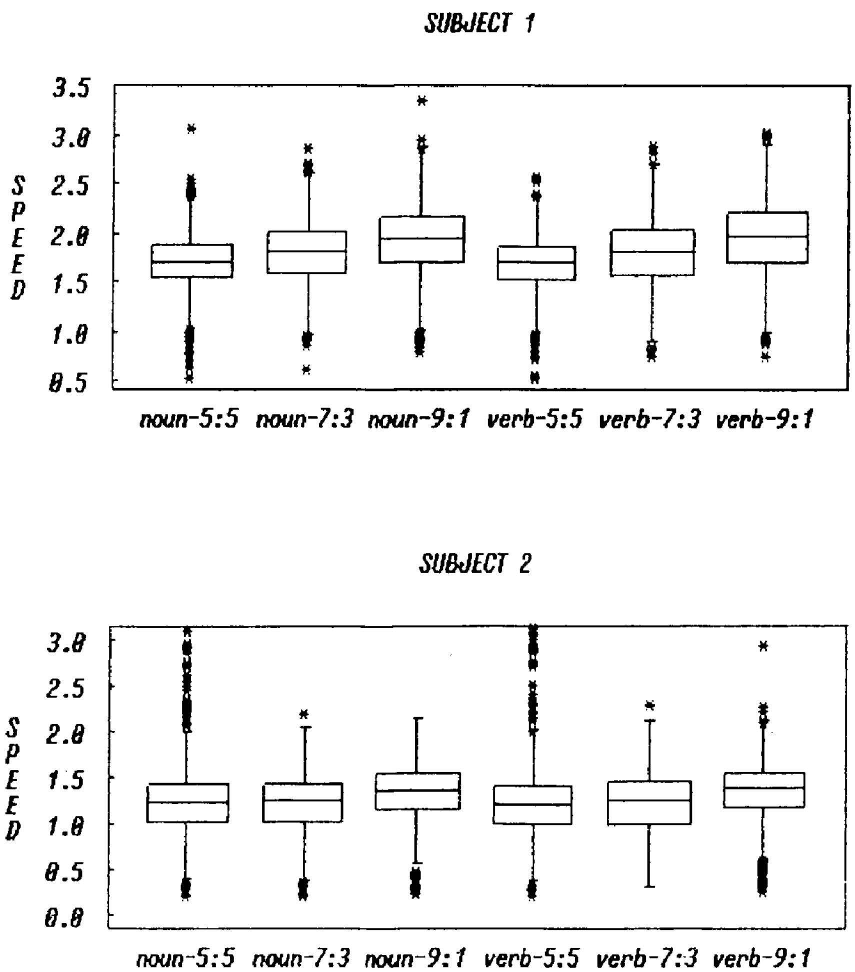
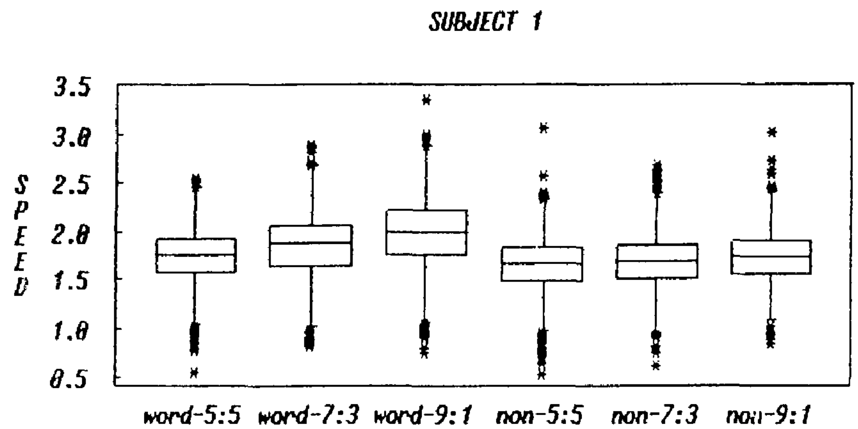


Figure 5. Speed versus Word Class by Signal:Noise Ratio



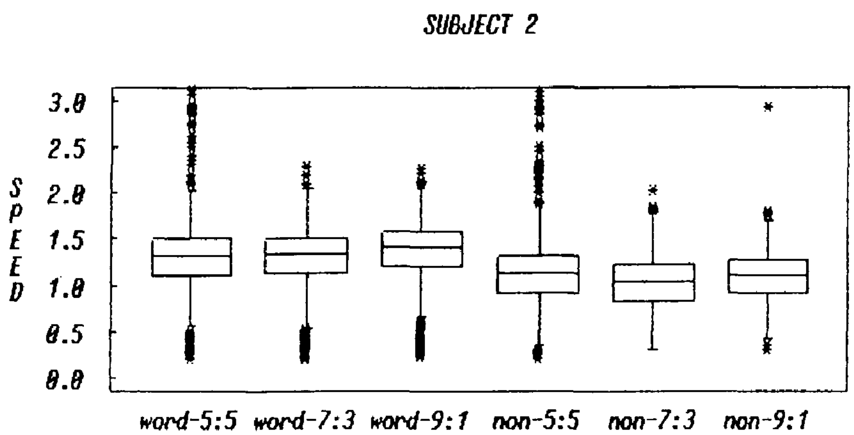


Figure 6. Speed versus Word/Nonword by Signal:Noise Ratio

linear decrease in speed, while for subject one, the loss in speed moving from 1.75 to 2.75 degrees of visual angle seems to be twice the speed loss from 0.75 to 1.75 degrees of visual angle.

Figure 1 suggests that there is no difference between visual fields. Speed measurements for nouns versus verbs (Figure 2) show no difference between the word classes at any visual angle for either subject. Words show a distinct speed advantage over nonwords in Figure 3. In all cases, the spread of speed remains fairly constant.

Figures 4 through 6 show speed over various signal to noise ratios for the same three factors. The situation here is less clear than the one depicted in the first three figures. For subject one, there is again a rather consistent pattern over S:N ratio changes. As S:N ratios increase from 50:50 to 90:10, speed increases. For subject two, there seems to be no difference between the 50:50 and 70:30 ratios, and a speed increase for the 90:10 ratio.

For subject one, speed is slightly higher for the LVF-RH presentations for 70:30 and 90:10 ratios (Figure 4). There is no noticeable difference between nouns and verbs for either subject (Figure 5). Large differences in both absolute results and pattern of results hold for words versus nonwords in Figure 6. At the 50:50 ratio, median speed seems equivalent for words and for nonwords for subject one. As the S:N ratios change, speed for words increases linearly, while speed for nonwords remains constant. For subject two, word speeds are faster at all S:N levels. For words, speed seems to increase slightly as S:N ratios increase. Nonword speeds seem to be stable, with decreasing variability.

In contrasting Figures 1 through 3, you will see that there is no difference between word class and visual field factors, and that the word/nonword differences compared to word class and visual field differences are slight. Word items are slightly faster than the word class and visual field factors, while nonword items are slightly slower. The same can be said about Figures 4 through 6. Figure 7 presents the boxplots for subject one for the visual field by word class by visual angle interaction. The boxplots are virtually identical across combinations of visual field and word class. A comparison of median values shows a consistent 10 to 15 millisecond advantage for RVF-LH presentations. This value is in line with callosal transmission estimates (Carmon, Nachshon, Isseroff, and Kleiner, 1972; Berlucchi, Heron, Hyman, Rizzolatti, and Umilta, 1971) and would correspond to the advantage the left hemisphere has in directly controlling the manual response. Overall, the differences that do seem to exist are for different visual angles of presentation and different S:N ratios, with the differences being as one would expect - slower responses as items are presented further from fixation, and faster responses as the proportion of words presented increases.

A comparison of the two hemispheres ability to learn to

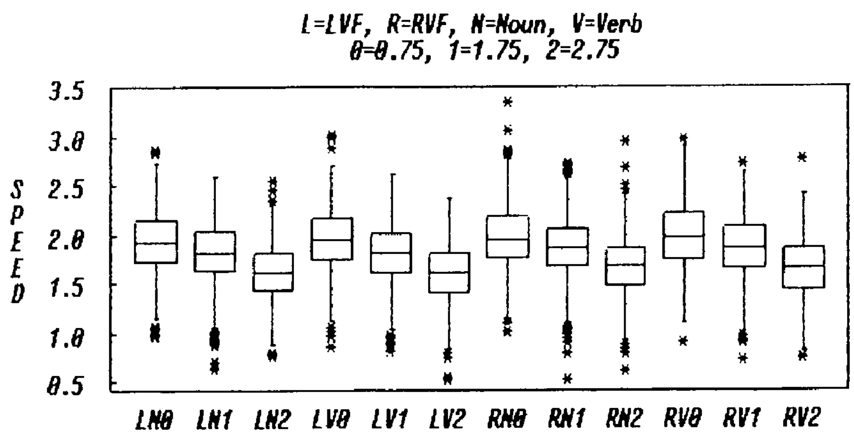


Figure 7. Speed for Subject 1 versus Visual Field by Word Class by Visual Angle

recognize nonword items was undertaken (see Appendix C for a description of adjusted reaction time data). No consistent patterns of learning were discovered.

CHAPTER III

EXPERIMENT 2: MULTIPLE SUBJECTS APPROACH

Method

Subjects

Thirty male undergraduates of the University of New Hampshire enrolled in psychology courses participated in the experiment in partial fulfillment of course requirements.

Material

The apparatus described in Experiment 1 was used in this experiment. All subjects took the Iowa Silent Reading Efficiency test (1973) and an examination measuring speed of closure, called the concealed words test (Copyright, Educational Testing Service, 1975). These measures were to be used as covariates in measuring the ability to identify degraded material.

Procedure

At the beginning of a session the subject was administered the reading and speed of closure tests. The subject was then instructed in the use of the equipment and was run through a practice block of 60 items. The method of ascending and descending limits was used during this block, with an initial presentation rate of 250 milliseconds, and changing in five millisecond increments depending on performance. The average of the last 20 trials of practice was used as the presentation rate for the 360 experimental trials. The experimental trials were arranged in six blocks of 60 trials each. There were 2 minute rest periods between blocks. Each trial was identical in format to those in Experiment 1.

The stimulus material in this experiment were five letter word and nonword items, vertically arrayed. Each subject saw material based on the following three factors:

1) word class (noun, mixed, verb)

2) word frequency (high, medium, low)

3) visual field (left, right)

These three factors were completely crossed, yielding 18 conditions. There were 20 stimulus items per condition, 10 words and 10 nonwords. Nonword items were created from word items in the manner described in Experiment 1. With the exception that nonword items were always presented in the visual field opposite of their matching word item, the order of presentation was completely randomized.

Three levels of word frequency were created based on the naming latencies versus word frequency counts figure in Swift (1977). High frequency words occurred 21 or more times per million, medium frequency words occurred 5 to 20 time per million and low frequency words occurred 0 to 4 times per million, based on the word corpus of Kucera and Francis (1967).

Word items were divided into three categories of word class. Nouns were items whose word class was purely nominal. Verbs were items whose word class was purely verbal.

Mixed items were those words whose use was a mixture of nominal and verbal (e.g., COAST). Category membership was determined by the results of a word usage survey conducted among Introductory Psychology students. These students wrote sentences using the first meaning that came to mind for 180 words. Pure nouns and pure verbs were words whose use in the survey was entirely nominal or verbal. Words whose usage was in the range of 60%-40% either nominal or verbal were designated mixed items.

A visual offset of 1.75 degrees from fixation and a signal to noise ratio of 50:50 was used for this experiment. As in the previous experiment, a key press to indicate word/nonword was made by the index finger of the subject's preferred hand. Subjects were asked to make a decision as rapidly and as accurately as possible.

Results

One subject's data was thrown out of the analyses owing to excessive errors in equipment performance (keyboard bounce yielding false responses). Of the remaining 29 subjects, three were eliminated because of negative handedness scores, indicating left-hand preference. The remaining subjects were all right-handed, with a mean and median handedness score of 68.

The standardized reading scores of the remaining 26 subjects were calculated and were found to be significantly higher than the mean standard score for Grade 11, $t(25)=5.07$, $p<.01$. The mean score for the concealed words test was significantly lower than that for adults, $\underline{t}$ (25)=-3.00, $\underline{p}$ <.02, but was not significantly different from that for Grade 12 males, $\underline{t}$ (25)=0.25, $\underline{p}$ >.39.

The three measures chosen to be used as classification or covariate measures were unrelated. The correlation between handedness and reading efficiency was the largest, $\underline{r}$ = -0.1984. The remaining two correlations were small, $\underline{r}$ = 0.0187 for concealed words test score and handedness, and $\underline{r}$ = 0.0479 for reading efficiency score and concealed words test score.

A total of 1.4% of the remaining 9360 trials for 26 subjects were coded as missing, replacing each reaction time with the mean reaction time of the cell for that subject. Missing data was classified as such because of extremely fast reaction time scores, usually under 50 milliseconds, indicative of keyboard bounce. In addition, two errors in the stimulus material required elimination of responses to those items.

As the only between groups factor in the design was subjects, an analysis of covariance was not run. The only factor that might be affected was subjects, and would not be tested in the mixed model ANCOVA. A regression was run using handedness, reading efficiency and concealed words test scores to predict speed of response. All three covariates were significant variables in the equation, but the effect on the error term was small. The amount by which the multiple r-square would be reduced if handedness, reading or concealed words test scores were removed from the regression equation is 0.00145, 0.031, and 0.00292, respectively. Using the results of the regression, one can calculate adjusted speed scores, removing the effects of the covariates. There is no significant difference in speed between subjects (an F-ratio near zero), and there is no change in the pattern of significant results in the within groups factors of an ANOVA with adjusted speed as the dependent variable when compared to the results of an ANOVA using speed as the dependent variable. Subsequent discussion will be based on the ANOVA using speed as the dependent variable (All of the following conventional F-ratios are supported by Geisser-Greenhouse conservative F-ratios or adjusted F-ratios, Kirk, 1982, page 261).

The results of a repeated measures ANOVA are displayed in Table 1. There are main effects for frequency, visual field and word/nonword.

The frequency effect is a reflection of high and medium frequencies differing from low frequency words (mean speed values of 0.87, 0.88, and 0.83, respectively). This result is consistent with the frequency effect reported in Bozak (1978).

The left visual field has a faster mean speed than the right visual field (0.87 and 0.85, respectively). Remembering that visual fields are mapped to contralateral hemispheres, this says that the right hemisphere responds <u>more</u> rapidly than the left hemisphere.

Table 1

Analysis of Variance for Experiment 2

SOURCE	ERROR TERM	df	MEAN SQUARE	F
GRAND MEAN	s	1	6936.825684	691.73**
SUBJECT(s)		25	10.028193	
FREQUENCY(f)	sf	2	2.205030	27.46**
CLASS(c)	sc	2	0.121260	1.78
VISUAL FIELD(v)	sv	1	0.473911	6.28*
WORD/NONWORD(w)	sw	1	40.319729	121.84**
sf		50	0.080301	
sc		50	0.067970	
fc	sfc	4	0.342834	5.35**
sv		25	0.075493	
fv	sfv	2	0.433649	9.24**
cv	scv	2	0.057439	0.82
sw		25	0.330919	
fw	sfw	2	1.513161	25.19**
cw	scw	2	0.077210	2.34
vw	svw	1	0.079711	1.32
sfc		100	0.064090	
sfv		50	0.046945	
scv		50	0.070119	
fcv	sfcv	4	0.143197	2.90*
sfw		50	0.060080	
scw		50	0.033036	
fcw	sfcw	4	0.014115	0.22
svw		25	0.060397	
fvw	sfvw	2	0.071133	1.32
cvw	scvw	2	0.354000	5.45**
sfcv		100	0.049346	
sfcw		100	0.063148	
sfvw		50	0.053956	
scvw		50	0.064954	
fcvw	sfcvw	4	0.150304	2.72*
i(fcvw)	si(fcvw)	324	0.178282	3.12**
sfcvw		100	0.055228	
si(fcvw)		8100	0.057059	

Note: The dependent variable is speed which is defined as 1000/RT.
* $p < .05$
** $p < .01$

Words are responded to more rapidly than nonwords (0.93 versus 0.80). On average, there is a 201 millisecond advantage for word items over nonword items.

The remaining significant interactions involve frequency or word class and can be found in the significant 4-way interaction described in Figure 8. Figure 8 illustrates a curious phenomena. The medium frequency noun items show a tremendous speed improvement over other items. It is this mean speed value that accounts for the slight rise in speed for medium frequency items in the frequency main effect. This rise for medium frequency items occurs for both words and nonwords, though the frequency effect is only evident for word items. It occurs in both visual fields, but is most pronounced in the LVF-RH. Differences in word class are also more pronounced in the LVF-RH, at least at high frequency levels.

When breaking down speed values by each cell of the four-way interaction by subject, it can be seen that some subjects have extremely low scores for high frequency nouns, rather than extremely fast speed scores for medium frequency nouns (Table 2). These means are the result of a few extreme RT values for some subjects, RT values as high as 5000 milliseconds. If we consider the mean speed values for each subject, collapsed over all cells, we see that subjects 9, 16, and 18 have slow average speed scores (Table 3). If we rerun the ANOVA dropping these subjects, we obtain the source table listed in Table 4.

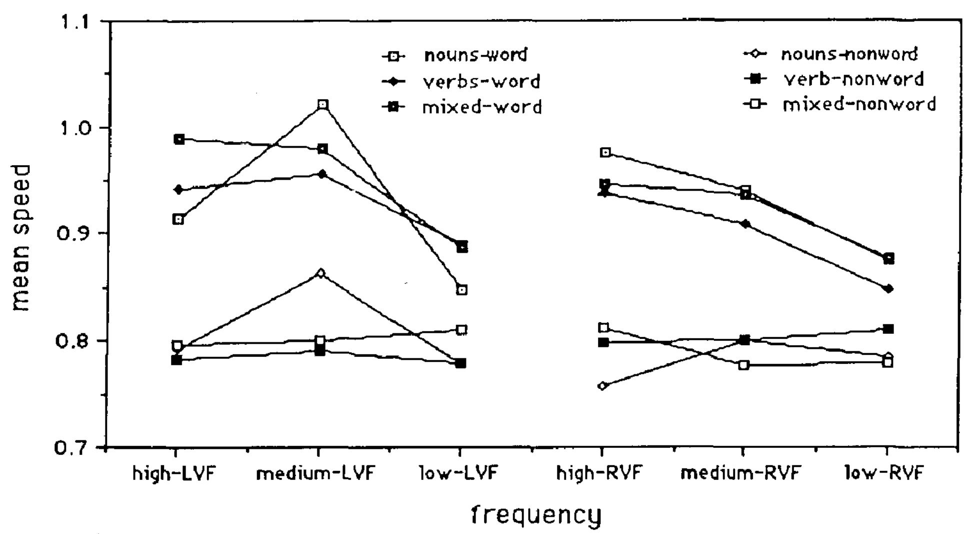


Figure 8. *Speed versus Frequency by Word Class by Word/Nonword by Visual Field*

Table 2

Mean Speed by Subject for High and

Medium Frequency Noun Word Items in LVF

Subject	High Frequency	Medium Frequency
1	0.96693	0.98005
2	1.00291	1.21313
3	0.75134	0.98526
4	0.77292	0.75416
5	0.81920	0.99559
6	0.93016	1.22373
7	0.86238	0.91982
8	1.23201	1.25847
9	0.80983	0.76899
10	0.93781	1.01193
11	0.79169	0.96705
12	1.09859	1.14326
13	0.70121	0.86814
14	1.30276	1.31711
15	1.07797	1.26981
16	0.64525	0.70108
18	0.67272	0.82134
20	1.06939	1.35525
21	1.03590	1.03268
22	0.69241	0.95139
23	0.78746	0.88155
26	0.91303	0.97359
27	1.00124	1.21081
28	0.92826	0.98388
29	0.90077	0.94397
30	1.05496	0.88777

Table 3

Mean Speed by Subject

Subject	Mean Speed
1	0.826
2	1.075
3	0.747
4	0.719
5	0.742
6	0.934
7	0.733
8	1.262
9	0.696
10	0.952
11	0.743
12	0.860
13	0.751
14	1.162
15	0.952
16	0.564
18	0.709
20	1.137
21	0.864
22	0.776
23	0.740
26	0.794
27	1.022
28	0.983
29	0.844
30	0.794

Table 4

Analysis of Variance for Experiment 2

After Removing 3 Slow Subjects

SOURCE	ERROR TERM	df	MEAN SQUARE	F
GRAND MEAN	s	1	6511.186523	744.78**
SUBJECT(s)		22	8.742482	
FREQUENCY(f)	sf	2	1.993127	27.52**
CLASS(c)	sc	2	0.233340	3.84*
VISUAL FIELD(v)	sv	1	0.248561	3.11
WORD/NONWORD(w)	sw	1	39.608593	122.92**
sf		44	0.072412	
sc		44	0.060740	
fc	sfc	4	0.473233	8.26**
sv		22	0.079897	
fv	sfv	2	0.365717	8.52**
cv	scv	2	0.097291	1.43
sw		22	0.322221	
fw	sfw	2	1.532514	27.96**
cw	scw	2	0.069388	2.04
vw	svw	1	0.014488	0.24
sfc		88	0.057291	
sfv		44	0.042899	
scv		44	0.068139	
fcv	sfcv	4	0.167978	3.55**
sfw		44	0.054817	
scw		44	0.034006	
fcw	sfcw	4	0.008656	0.13
svw		22	0.059640	
fvw	sfvw	2	0.035719	0.64
cvw	scvw	2	0.310869	5.32**
sfcv		88	0.047336	
sfcw		88	0.068747	
sfvw		44	0.056118	
scvw		44	0.058476	
fcvw	sfcvw	4	0.097226	2.05
i(fcvw)	si(fcvw)	324	0.176452	3.31**
sfcvw		88	0.047333	
si(fcvw)		7128	0.053268	

Note: The dependent variable is speed which is defined as 1000/RT.
 * $p < .05$
** $p < .01$

The overall frequency effect shows high and medium frequency items virtually identical, with a dramatic drop in speed of response for low frequency items (mean speed values of 0.901, 0.903, and 0.856, respectively). The visual field main effect is gone, but there is a main effect of word class, where noun and mixed items are nearly identical, together significantly different from verb items (mean speed values of 0.891, 0.893, and 0.876, respectively). The dramatic word/nonword difference remains (0.96 versus 0.82).

Figure 9 shows the 3-way interaction of frequency by word class by visual field. Here we still see the elevated speed value for medium frequency noun items. The difference in speed values for high and medium frequency noun items in the LVF-RH represent a difference of 108 milliseconds. Comparing the LVF-RH and RVF-LH noun curves in this figure, however, leaves room for doubt whether the issue is one of speeded responses for medium frequency noun items or slow responses for high frequency noun items. There is no obvious pattern evident in the boxplots of speed values for the items classified in the cells in question in Figures 10 through 13. The only factor of note is the much more variable nature of the medium frequency noun items, regardless of visual field of presentation.

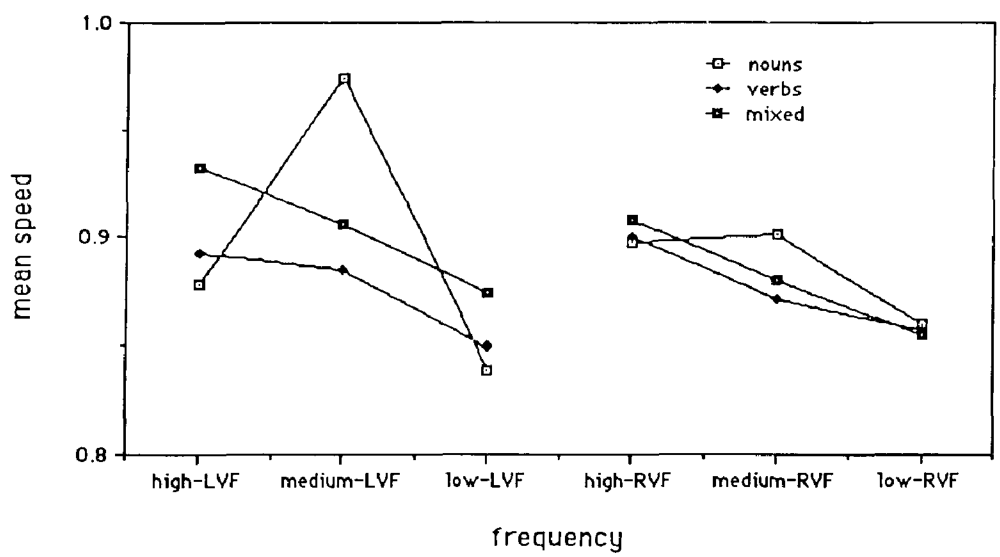


Figure 9. Without Slow Subjects, Speed versus Frequency by Word Class by Visual Field

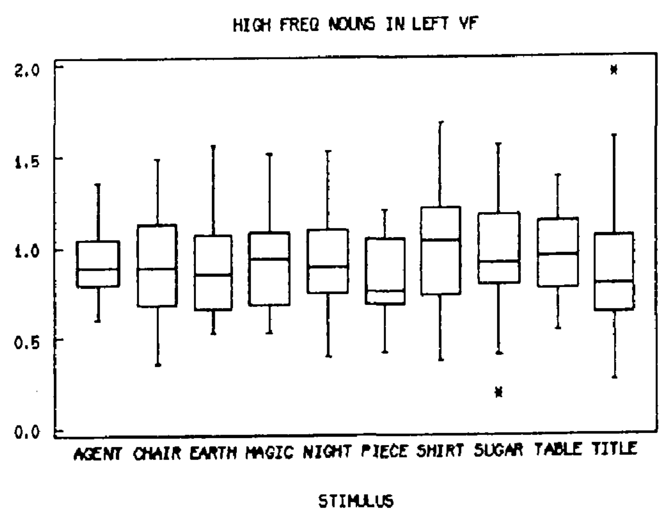


Figure 10. Speed of High Frequency Nouns in LVF

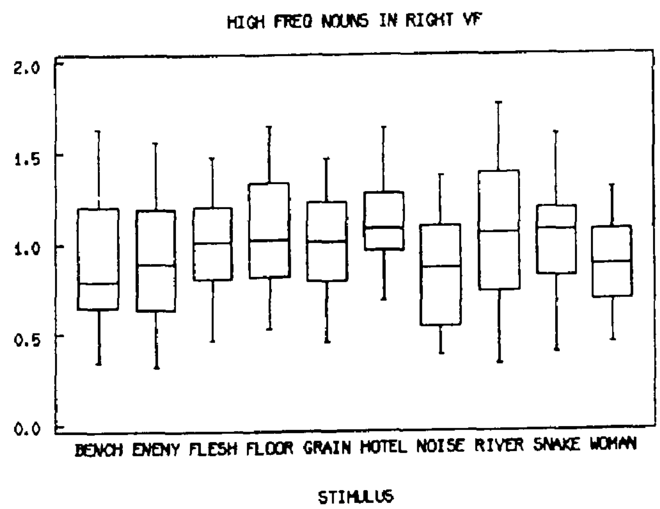


Figure 11. Speed of High Frequency Nouns in RVF

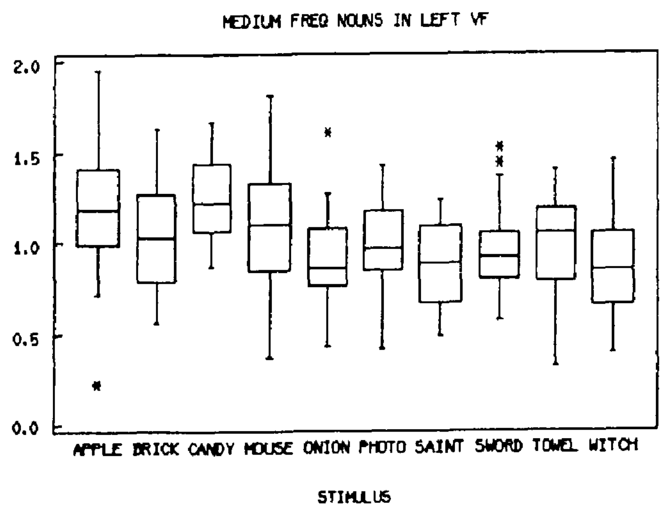


Figure 12. Speed of Medium Frequency Nouns in LVF

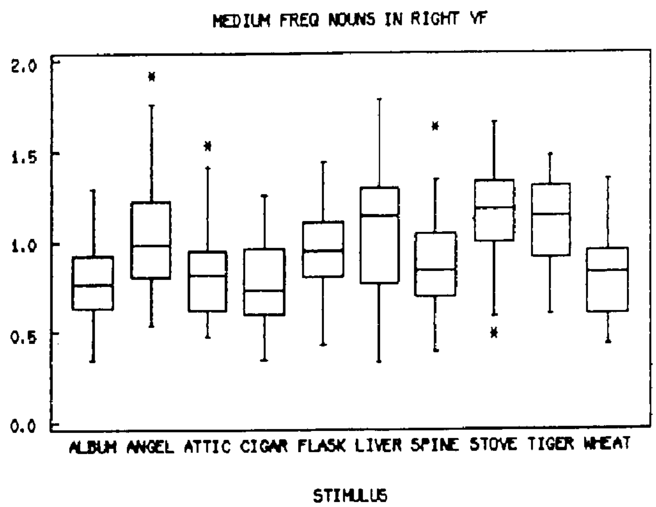


Figure 13. Speed of Medium Frequency Nouns in RVF

CHAPTER IV

DISCUSSION AND CONCLUSIONS

Two experiments designed to understand lexical access by examining the locus of the word frequency effect and the possible interaction with grammatical class were conducted. The first experiment focussed on word class differences between hemispheres for high frequency words. No speed of response differences were found, though subject one responded much more rapidly than subject two. No differences in correctness of response for word items was found, although subject one responded at a higher error rate than did subject two (9.85% versus 2.55%). Some slight difference in error rate for verb-derived nonword items was found, 24.70% versus 31.60% for LVF-RH and RVF-LH presentations, respectively, for subject one and 20.60% versus 15.50% for LVF-RH and RVF-LH presentations, respectively, for subject two. Error rates for noun-derived nonword items presented to either hemisphere were identical, 23.75% and 7.75% for subjects one and two, respectively.

Concerns over the presentation parameters in Bozak (1978) led to a manipulation of visual angle of presentation. Response deteriorated with increasing visual angle, and the deterioration was consistent for both visual fields. The deterioration in speed of response was a constant with increasing visual angle, while variability of response remained fairly constant. The magnitude of the deterioration was larger for subject one than subject two. Changes in signal to noise ratio resembled changes in visual angle. Speed increased by a constant for subject one, while for subject two, speed increased only for the highest signal to noise ratio. Variability remained constant for subject two, while it increased with increasing signal to noise ratio for subject one, the result of many more very speeded responses to word items.

Experiment two was a typical inferential factorial design, using a lexical decision task and varying word frequency, word class, and visual field of presentation. A strong word frequency effect was found, especially contrasting high and medium frequency items with low frequency items, with no evident frequency effect for nonword items, based on the frequencies of the words from which they were derived. Words maintained a significant speed advantage over nonword items.

When considering the question of word class, and especially its interaction with visual field of presentation, considerable confusion exists due to the abnormally high performance for medium frequency noun items, especially when compared to high frequency noun items. This performance is not the result of a few aberrant responses, but simply overall elevated performance. A number of pieces of evidence lead to the conclusion that the average speed for medium frequency noun items is abnormally high rather than the conclusion that average speed for high frequency noun items is depressed.

Consider the frequency by word class interaction. Verb and mixed class items yield consistently slower speeds with lower frequency. Medium frequency noun items show a speed increase over high frequency nouns more than twice the size of the drops for verb and mixed class, while the difference between high and low frequency noun items is similar to the differences between high and low frequency verb or mixed items.

Second, examination of figure 9 again illustrate how abnormal the medium frequency point seems to be. In the RVF-LH, it is the medium frequency noun point which seems to prevent the three curves from being nearly identical. While the medium frequency verb point in the LVF-RH seems slightly elevated, the medium frequency noun point is highly abnormal. If that point were coincident with the medium frequency verb point, then the frequency by word class interaction would likely disappear. Overall, then, there would be a frequency effect for each word class, with nouns and verbs being most alike, with mixed class items responded to more rapidly.

There does not seem to be a clear explanation of why the medium frequency noun word items should be so out of line with the rest of the data. Median response speeds for the medium frequency items are more variable than other categories, and though the error rates are lower for the LVF-RH medium noun items, it is not significantly lower. Table 5 contains the frequencies of correct and incorrect responses for experiment 2.

The early reports of word class differences between the left and right hemispheres (LH and RH) were prompted by Gazzaniga's reporting that the right hemisphere of commissurotomy patients, while mute, could process simple nouns and some adjectives, but could not handle verbs (1970). The studies since then have not been able to organize the different abilities of the two hemispheres. The primary focus has been on differing noun forms (agentive nouns, category-ambiguous nouns, simple nouns, concrete nouns, abstract nouns, high and low imagery nouns) with quite mixed results, though verbs and adjectives have also been examined, again with mixed results. Some of these studies have noted frequency interactions as well.

Caplan, Holmes and Marshall (1974) reported a word class by visual field interaction, that agentive nouns (verb-derived nouns) were better recognized than pure or category-ambiguous nouns in the LH, and agentive and category-ambiguous nouns were recognized better than pure nouns in the RH. Ellis and Shepard (1974) reported LH superiority in recognition of both concrete and abstract words, though in the RH, concrete words were better recognized than abstract words. Marshall and Holmes (1974) found nouns better recognized than verbs, particularly for low

Table 5

Correct Responses and Errors

Words

		LVF		RVF	
Frequency	Word Class	Correct	Errors	Correct	Errors
High	Noun	182	78	207	53
High	Verb	200	60	216	43
High	Mixed	226	34	214	46
Medium	Noun	219	41	198	61
Medium	Verb	189	70	207	53
Medium	Mixed	218	41	206	54
Low	Noun	165	95	178	82
Low	Verb	179	77	172	86
Low	Mixed	190	70	205	54

Nonwords

		LVF		RVF	
Frequency	Word Class	Correct	Errors	Correct	Errors
High	Noun	230	30	221	39
High	Verb	217	43	212	48
High	Mixed	211	49	217	43
Medium	Noun	198	62	224	35
Medium	Verb	222	37	216	44
Medium	Mixed	178	54	213	47
Low	Noun	185	22	223	36
Low	Verb	217	43	239	20
Low	Mixed	231	29	194	40

frequency items, and particularly in the LH. Hines (1976) found a LH advantage for high frequency abstract nouns over high frequency concrete nouns, with no lateral differences for low frequency abstract and concrete nouns. Day (1977) found no lateral differences for concrete nouns and LH superiority for abstract nouns, replicated by Mannhaupt (1983).

In 1979, Day extended his study. He replicated and extended his finding of no lateral difference for concrete nouns by finding no lateralized RT differences for high imagery nouns and adjectives. High imagery verbs and low imagery nouns, adjectives and verbs were recognized as words more rapidly when presented to the LH.

Hatta (1977) contrasted abstract and concrete Kanji symbols and found concrete Kanji more correctly recognized than abstract Kanji in the RH (though there was a RH superiority for Kanji overall). Other reports that the RH is capable of orthographic analysis and not phonetic analysis (Levy, 1978; Zaidel, 1978) support this finding, as Kanji is essentially logographic.

Orenstein and Meighan (1976) failed to replicate Ellis and Shepherd, and Shannon (1979) failed to replicate Day (1977). Koff and Riederer (1981) find absolutely no lateral differences for pure nouns, agentive nouns or category ambiguous nouns. They also do not find a lateralization of frequency. Jackman (1985) found that while verbs were equally reported in both hemispheres, nouns did better than verbs in the LH and slightly worse than verbs in the RH. Interestingly, Elman, Takahashi, and Tohsaku (1981) also found a hemispheric asymmetry in favor of nouns over verbs in the RH, with no difference in the LH. Their stimuli were Kanji.

The present findings partially support a number of these studies. The noun facilitation effect reported in the LH by Marshall and Holmes (1974) is supported. Category-ambiguous words were recognized more rapidly than verbs or nouns in the RH, partially supporting Caplan, Holmes and Marshall (1974). This is in direct contrast to Bozak (1978), who reported better recognition for nouns than category-ambiguous words in the RH for high and medium frequency items, and the opposite finding for the LH with no lateral differences for low frequency items. The current findings of no interaction between visual field and word class supports Koff and Riederer (1981). The current findings of a frequency by visual field interaction is in contrast to Koff and Riederer.

While little agreement seems to exist between these researchers, the possibility of imagery, rather than word class, as a significant factor is suggested by Jackman (1985) and Hatta (1977). Most RH findings are for high imagery items (or concrete items, as the two scales are highly correlated; Paivio, Yuille and Madigan, 1968), and if the LH is found to be superior, it is when considering low imagery items.

A little data-snooping, in order to test the imagery hypothesis, was carried out. Sixteen items in experiment two were identified for which imagery values were available (Paivio, Yuille, and Madigan, 1968). A regression using handedness score, reading test score, concealed words test score, objective word frequency, visual field, word/nonword, imagery score, concreteness measure and meaningfulness value to predict speed was run. The 16 identified items and their respective nonwords for 26 subjects were used. A significant regression equation was found, $\underline{F}(10,795) = 16.42$, $\underline{p} < .01$, with reading score, word/nonword, objective frequency and concreteness measure as predictors, though the model only accounted for 17.12% of the variance in the data.

In Bozak (1978), several methodological difficulties were encountered, even though a typical tachistoscopic paradigm was used. In the present experiments, some differences with the published literature are again found. The median reaction times found here were very different from those reported in the literature. Typically reported average reaction times are 819 and 867 milliseconds (Oldfield and Wingfield, 1964; Oldfield and Wingfield, 1965), 398 milliseconds (Lorch, 1986), 637 milliseconds (Day, 1979), 643 milliseconds (Whaley, 1978), and 653 milliseconds (Segui, Mehler, Frauenfelder, and Morton, 1982). Subject one in experiment 1 had a median RT of 553 milliseconds, subject two had a median RT of 775 milliseconds. In experiment 2, the median RT was 1213 milliseconds. The average RT for

Bozak (1978) was 1474 milliseconds. While subject one seems in line, and subject two is in fact faster than the Oldfield and Wingfield times, the median RT for experiment two is twice as slow.

In addition, subjects in experiment 2 do slow down by about 83 milliseconds over the course of the 360 trials. However, when we look at the average speed per block of trials, there is no significant reduction in speed, $F(5,150) = 0.17$, $p > .05$. Similarly, there are no differences in the number of correct or incorrect responses per block of trials, $F(5,150) = 1.45$, $p > .05$, $F(5,150) = 0.94$, $p > .05$, respectively. The subjects are simply slow.

Many experimenters, beginning with Oldfield and Wingfield (1964), report that RT is linearly related to log frequency. Whaley (1978), Bradley (1978), Segui, Mehler, Frauenfelder, and Morton (1982), Gordon and Caramazza (1982), and Balota and Chumbley (1984) all use log frequency when examining RT. In experiment 2, RT is linearly related to the log of objective word frequency, with an intercept of 1360.496 and a slope of -29.453. The slope is significantly different than zero, $t(9228) = 136.15$, $p < .01$. This regression is significant, $F(1,9228) = 13.91$, $p < .01$.

A finding of differential processing of words between the two hemispheres would lend support to a model of lexical retrieval which relied upon multiple lexicons to support parallel processing of verbal material. The lack of unambiguous support for such lateralized processing of lexical items in these studies and in others cited does not rule out the notion of multiple lexicons, as multiple lexicons might exist within one hemisphere. However, two studies, Gordon and Caramazza (1982) and Segui, Mehler, Frauenfelder and Morton (1982), failed to replicate the findings of Bradley (1978).

A total of 8 experiments in both English and French fail to find differences in response to items of closed- and open-classes. Bradley had demonstrated a frequency effect for open-class items only. Segui, et al. find identical frequency effects for the two classes, when there is complete overlap of frequency range for the items chosen from the two classes. Gordon and Caramazza found different frequency effects for closed- and open-classes which they attribute to the different frequency ranges covered by items chosen from the two classes. Where there is overlap in the range of frequencies, the frequency effect is the same.

They suggest that Bradley's findings are an artifact of the overrepresentation of closed-class items in the higher frequency range, where they discover a floor effect for RT. They further find that function of RT with log frequency is not linear, but is actually a composite of two linear functions of RT and log frequency, with an inflection point occurring at a log frequency of about 2.5 (or in the frequency range of 300 to 399). Below this inflection point the function is linear and negative. Above this point the function is linear and flat.

Only two items in the experiment 2 of the current study exceeded this range. Following Gordon and Caramazza and Segui, et al., we would not expect to find a nonlinear frequency effect. While the intercept for the regression for experiment 2 reported above was much larger than those reported by Segui, et al. (they reported intercepts between 658 and 704), their slopes were similar (-16 to -28.4).

Morton, in his revised logogen model (1982), attributed the word frequency effect in lexical decision tasks to the operation of the cognitive system and the structure of the semantic and associative components, and not the logogen system. He further suggested that the effect was an index of some other property of the cognitive system rather than being directly represented. Investigations of the word frequency effect have found differences in the strength of the effect, or even its presence, dependent upon the subject's task.

Balota and Chumbley (1984) best present the problem of lexical access and word frequency. They performed three experiments using the same stimuli and examined the effect of five lexical variables. The word frequency effect was virtually absent in a category verification task (yes/no decision upon the validity of a category-exemplar relationship), significantly larger in a naming task, and significantly larger yet in a lexical decision task. The task used to assess lexical access affected the magnitude of the word frequency effect. This was true even though lexical access is a necessary precondition for all three reported tasks.

A category verification task would require additional cognitive processing to determine the validity of associating a particular word's concept with a category. While word frequency could affect lexical access, lexical access is a small part of the overall process, and the effect of word frequency would be hidden.

A task is needed which minimizes postaccess processing. As described above, lexical decision requires significant postaccess processing, thus exaggerating the frequency effect. A naming task, another popular tool to investigate word frequency, may be affected by production processing after lexical access. Alternatively, naming may bypass lexical access altogether, using a direct grapheme-phoneme translation (Swift, 1977). Clearly, the interpretation of results from naming tasks is complicated. A word reading task would require lexical access, but would have minimal postaccess processing requirements. Lorch (1986) had subjects indicate when they had completed reading a single word item by pressing a key. Subjects were warned that they would randomly be asked to recall a word, in order to ensure that subjects actually read the word rather than responding to its onset. Errors on random recall were small, 2.2% of trials. Lorch found a frequency effect for long words (8 to 14 letters in length) and no effect for short words (3 to 5 letters in length). The effect, though, is about twice the size as one would expect, given the linear RT by log frequency relationship described above. While minimizing postaccess processing, it is not a pure measure of access.

We are left, then, little better off than when we began. We began by wishing to understand lexical access better by uncovering more about what seemed a fundamental effect guiding the structure of the lexicon. Models of lexical access (Forster and Morton) were created by an examination of the robust effect of word frequency. These models attempted to structure the lexicon for access so as to address the issue of word frequency effects. Evidence that the RH has linguistic capabilities that might be related to word frequency provided a means of understanding more fully the manner in which the lexicon is structured. Mere exposure was ruled out as a principle of structure on that basis. But the studies conducted provided no evidence of lateralized differences in effects of word frequency. The evidence of frequency effects interacting with word class membership reached a level of significance, though the responses of subjects to medium frequency noun items accounted for the interaction. The mixture of results adds to an already confusing set of published results concerning word frequency, lateralization and word class.

If we have returned to a starting point, the issue of mere exposure carries significantly more weight than it had previously. The study of Foos, Lero, McDonnell, and Sabol (1985), which asked subjects to recall words based on subjective frequency, gains importance. Subjects were asked to recall 60 words. One set of subjects were asked to list the 60 most frequent words, 10 at a time. A second set of subjects were asked to list the 10 most frequent of the 100 most frequent words, followed by the 10 most frequent of the second 100 most frequent words, and so on until 60 words were listed. The correlations of these listings to objective frequency counts was significant, while the correlations of these listings to number of meanings was not significantly different from zero.

Either an ordered or an unordered lexicon would be able to demonstrate a word frequency effect on the basis of mere exposure. The fact that subjects could skip the 11th through 100th most frequent words in order to locate the 101st through 110th most frequent words, and so on, argues for an ordered lexicon.

While Morton's logogen system calls for direct access based on some passive analysis of an item, some means of connecting this system with an ordered lexicon must be maintained over time. Some process of progressive refinement based upon mere exposure would be a simple means of relating the two. Kiss (1973) describes one such method of creating structure out of random stimulation by increasing associative links between items based on the co-occurrence of words in the environment. A simulation of such a process, when fed transcripts of the speech of children, created a structure which progressively separated nouns, verbs, adjectives, pronouns, determiners, and prepositions. Research should now be directed towards elaborating the connection between these two systems.

It is not necessary to give up entirely on the notion of lateralized contributions to lexical access. It is possible that the predominant finding of LH superiority of language is a function of the cognitive processing being located in the LH. The actual lexical access method might well be situated in the RH. Searleman's review of the language capabilities of the RH (1983) provides a number of clues. The RH is superior to the LH for initial stages of letter processing. When presented with degraded stimuli, the RH was more efficient at extracting relevant visual features of letters. The increasing superiority of the RH to name items presented in increasingly perceptually difficult typefaces has led to support for the notion of the RH as superior at global processing abilities. Dichotic tasks also provide evidence of the RH as a superior perceptual processor.

In summary, the line of evidence relating word frequency, lateral differences and word class differences to lexical access mechanisms is ended. Specifically, the original hypothesis of this study is not supported and the results of Bozak (1978) are not replicated. An examination of the published literature since the experiments were performed suggests that the translation of visual input to lexical access code is an issue separate from the cognitive processing which gives rise to effects of frequency and possible interactions with other lexical factors (word class, imagery, meaningfulness, and so on). Lines of investigation into two areas must be developed. These areas are (1) the method of generation of a lexical access code (which may or may not involve the RH) and, (2) the relationship between a rapidly calculated direct access code and an ordered lexicon.

REFERENCES

Balota, D. A., & Chumbley, J. I. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. Journal of Experimental Psychology: Human Perception and Performance, 10, 340-357.

Becker, C. A., & Killion, J. H. (1973). Interaction of visual and cognitive effects in word recognition. Journal of Experimental Psychology: Human Perception and Performance, 3, 389-401.

Berlucchi, G., Heron, W., Hyman, R., Rizzolatti, G., & Umilta, C. (1971). Simple reaction times of ipsilateral and contralateral hand to lateralized visual stimuli. Brain, 94, 419-430.

Bozak, D. A. (1978). The word frequency effect and hemispheric specialization. Unpublished master's thesis, University of New Hampshire.

Bradley, D. C. (1978). Computational distinctions of vocabulary type. Unpublished doctoral dissertation, Massachusetts Institute of Technology.

Caplan, D., Holmes, J. M. & Marshall, J. C. (1974). Word classes and hemispheric specialization. Neuropsychologia, 12, 331-337.

Carmon, A., Nachshon, I. Isseroff, A., & Kleiner, M. (1972). Visual field differences in reaction times to Hebrew letters. Psychonomic Science, 28, 222-224.

Carroll, J. B. & White, M. N. (1973). Word frequency and age of acquisition as determiners of picture-naming latency. Quarterly Journal of Experimental Psychology, 25, 85-95.

Cirrin, F. M. (1984). Lexical search speed in children and adults. Journal of Experimental Child Psychology, 37, 158-175.

Day, J. (1977). Right hemisphere language processing in normal right handers. Journal of Experimental Psychology: Human Perception and Performance, 3, 518-528.

Day, J. (1979). Visual half-field word recognition as a function of syntactic class and imageability. Neuropsychologia, 17, 515-519.

Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). Manual for kit of factor-referenced cognitive tests. Princeton, NJ: Educational Testing Service.

Ellis, H. D., & Shepherd, J. W. (1974). Recognition of abstract and concrete words presented in left and right visual fields. Journal of Experimental Psychology, 103, 1035-1036.

Elman, J. L., Takahashi, K., & Tohsaku, Y. -H. (1981). Asymmetries for the categorization of kanji nouns, adjectives and verbs presented in the left and right visual fields. Brain and Language, 13, 290-300.

Farr, R. (Ed.). (1973). Iowa silent reading tests. New York, NY: Harcourt Brace Jovanovich, Inc.

Foos, P. W., Lero, S., McDonnell, P., & Sabol, M. A. (1985). Recall evidence for a frequency ordered lexicon. Bulletin of the Psychonomic Society, 23, 355-358.

Forster, K. I. (1976). Accessing the mental lexicon. In E. C. T. Walker & R. J. Wales (eds.), New approaches to language mechanisms. Amsterdam: North Holland Press.

Forster, K. I. (1982). Levels of processing and the structure of the language processor. In W. E. Cooper & E. C. T. Walker (eds.), Sentence Processing: Psycholinguistic studies presented to Merrill Garrett (pp. 27-87). Hillsdale, NJ: Erlbaum.

Gazzaniga, M. S. (1970). The bisected brain. Appleton-Century-Crofts: New York.

Gordon, B., & Caramazza, A. (1982). Lexical decision for open- and closed-class words: Failure to replicate differential frequency sensitivity. Brain and Language, 15, 143-160.

Hatta, T. (1977). Lateral recognition of abstract and concrete kanji in japanese. Perceptual and Motor Skills, 45, 731-734.

Hines, D. (1976). Recognition of verbs, abstract nouns and concrete nouns from the left and right visual half-fields. Neuropsychologia, 14, 211-216.

Jackman, M. K. (1985). The recognition of tachistoscopically presented words, varying in imagery, part of speech and word frequency, in the left and right visual fields. British Journal of Psychology, 76, 59-74.

Kirk, R. E. (1982). Experimental design: Procedures for the behavioral sciences (2nd ed.). Montery, CA: Brooks/Cole Publishing Company.

Kiss, G. R. (1973) Grammatical word classes: A learning process and its simulation. In G. H. Bower (Ed.), The psychology of learning and motivation: Vol. 7 (pp. 1-41). New York: Academic Press.

Koff, E. & Riederer, S. A. (1981). Hemispheric specialization for syntactic form. Brain and Language, 14, 138-143.

Kolson, C. (1961). The vocabularies of kindergarten children. Pittsburgh: The University of Pittsburgh Press.

Kucera, H., & Francis, W. N. (1967). Computational analysis of present-day American English. Providence, R. I.: Brown University Press.

Landauer, T. K. (1975). Memory without organization: Properties of a model with random storage and undirected retrieval. Cognitive Psychology, 7, 495-531.

Lennie, P. (1980). Parallel visual pathways: A review. Vision Research, 20, 561-594.

Levy, J. (1978). Lateral differences in the human brain in cognition and behavioral control. In P. Buser & A. Rougeul-Buser (eds.), Cerebral correlates of conscious experience. (pp. 285-293). Amsterdam: Elsevier.

Loftus, E. F. & Suppes, P. (1972). Structural variables that determine the speed of retrieving words from long-term memory. Journal of Verbal Learning and Verbal Behavior, 11, 770-777.

Lorch, Jr., R. F. (1986). Use of a word reading task for studying word recognition. Bulletin of the Psychonomic Society, 24, 11-14.

Mannhaupt, H. R. (1983). Processing of abstract and concrete nouns in a lateralized memory-search task. Psychological Research, 45, 91-105.

Marshall, J. C. & Holmes, J. M. (1974). Sex, handedness and differential hemispheric specialization for components of word perception. Journal of International Research Communications: Medical Science, 2, 1344.

Morton, J. (1969). The interaction of information in word recognition. Psychological Review, 86, 165-178.

Morton, J. (1970). A functional model for memory. In D. A. Norman (ed.), Models of human memory (pp. 203-254). New York: Academic Press.

Morton, J. (1982). Disintegrating the lexicon: An information processing approach. In J. Mehler, E. C. T. Walker, & M. Garrett (eds.), Perspectives on Mental Representation (pp. 89-109). Hillsdale, NJ: Erlbaum.

Oldfield, R. C., & Wingfield, A. (1964). The time it takes to name an object. Nature, 202, 1031-1032.

Oldfield, R. C., & Wingfield, A. (1965). Response latencies in naming objects. Quarterly Journal of Experimental Psychology, 17, 273-281.

Orenstein, H. B., & Meighan, W. B. (1976). Recognition of bilaterally represented words varying in concreteness and frequency: Lateral dominance or sequential processing? Bulletin of the Psychonomic Society, 7, 179-180.

Paivio, A., Yuille, J. C., & Madigan, S. A. (1968). Concreteness, imagery, and meaningfulness values for 925 nouns. Journal of Experimental Psychology, 76, 1-25.

Rabin, J. L., & Zecker, S. G. (1982). Phonemic code dependence varies with previous exposure to words. Poster presented at the meeting of the Eastern Psychological Association, Baltimore, MD.

Rosenzweig, M. R., & Postman, L. (1958). Frequency of usage and the perception of words. Science, 127, 263-266.

Searleman, A. (1983). Language capabilities of the right hemisphere. In Young, A. W. (ed.), Functions of the Right Cerebral Hemisphere (pp. 87-111). New York: Academic Press.

Segui, J., Mehler, J., Frauenfelder, U., & Morton, J. (1982). The word frequency effect and lexical access. Neuropsychologia, 20, 615-627.

Shannon, B. (1979). Lateralization effects in lexical decision tasks. Brain and Language, 8, 380-387.

Solomon, R. L., & Postman, L. (1952). Frequency of usage as a determinant of recognition thresholds for words. Journal of Experimental Psychology, 43, 195-201.

Stanners, R. F., Jastrzembski, J. E., & Westbrook, A. (1975). Frequency and visual quality in a word-nonword classification task. Journal of Verbal Learning and Verbal Behavior, 14, 259-264.

Swift, D. J. (1977). *The effects of context, word frequency and internal redundancy in reading and word perception.* Unpublished doctoral dissertation, University of New Hampshire.

Tukey, J. (1977). *Exploratory data analysis.* Reading, MA: Addison-Wesley Publishing Company.

Whaley, C. P. (1978). Word-nonword classification time. *Journal of Verbal Learning and Verbal Behavior*, *17*, 143-154.

Worden, P. E., & Sherman-Brown, S. (1983). A word-frequency cohort effect in young versus elderly adults' memory for words. *Developmental Psychology*, *19*, 521-530.

Zaidel, E. (1978). Lexical organization in the right hemisphere. In P. Buser & A. Rougeul-Buser (eds.), *Cerebral correlates of conscious experience.* (pp. 177-197). Amsterdam: Elsevier.

APPENDICES

APPENDIX A

PROGRAM CODE

```
;
;  THIS MODULE WAS WRITTEN TO HANDLE DISSERTATION EXPERIMENT
;  ONE.  IT WILL DISPLAY 5 LETTER WORDS AS PASSED TO IT FROM
;  A CALLING FORTRAN ROUTINE.
;
;  THIS ROUTINE IS PASSED THREE PARAMETERS:
;       1) IN REGISTERS HL IS THE VISUAL ANGLE ADDRESS
;       2) IN REGISTERS DE IS THE ADDRESS OF THE FIRST DATA
;          ITEM
;       3) IN REGISTERS BC IS THE ADDRESS OF THE HIGH BYTE
;          OF EXPOSURE DURATION OF THE TARGET ITEM.
;
;  IT ASSUMES THAT THERE ARE 100 TRIALS TO BE RUN AND THAT
;  THE ARRAY PASSED TO IT CONTAINS 100 ROWS BY 10 COLUMNS.
;  THE FIRST COLUMN IS THE VISUAL FIELD ("L" OR "R") OF
;  PRESENTATION.  THE SECOND COLUMN THROUGH THE SIXTH ARE
;  THE WORDS TO BE DISPLAYED (IN TERMS OF THE DECIMAL VALUE
;  OF THE ASCII CHARACTERS).  THE SEVENTH COLUMN CONTAINS
;  THE DECIMAL VALUE OF THE CORRECT RESPONSE TO THE TARGET.
;  COLUMN EIGHT WILL CONTAIN ;  THE RESPONSE MADE BY THE
;  SUBJECT.  COLUMNS NINE AND TEN WILL CONTAIN THE REACTION
;  TIME OF THE RESPONSE.  THE ARRAY SHOULD HAVE BEEN
;  DECLARED AS LOGICAL, THUS WILL TAKE UP 1000 BYTES OF
;  STORAGE.
;
;
        ENTRY   PRES
;
;
        KEYSTA  EQU     06H         ;KEYBOARD STATUS PORT
        KEYIN   EQU     00H         ;KEYBOARD DATA PORT
        MASTAT  EQU     0F1H        ;MA STATUS PORT
        MAOUT   EQU     0F0H        ;MA DATA PORT
;
;  SAVE THE PARAMETERS, LOAD THE COUNTER AND INIT THE
;  VISUAL DISPLACEMENT
;
PRES:   LD      (VISANG),HL         ;SAVE THE ADDRESS HOLDING
                                    ;VISUAL ANGLE
        LD      (DATA),DE           ;SAVE ADDRESS POINTING TO
                                    ;FIRST DATA ITEM
        LD      A,(BC)              ;SAVE THE HIGH ORDER
                                    ;EXPOSURE VALUE
        LD      (EXPOHI),A
```

```
        INC     BC
        LD      A,(BC)          ;SAVE THE LOW ORDER EXPOSURE
                                ;VALUE
        LD      (EXPOLO),A
        LD      A,01H
        LD      (COUNT),A       ;SET THE COUNTER TO 1
        CALL    SETVIS          ;SET UP (X,Y) COORDINATES
        CALL    DELAY7          ;BRIEF PAUSE AT BEGINNING
        CALL    DELAY7
;
;  BEGIN THE MAIN ROUTINE
;
BEGIN:  LD      HL,(DATA)       ;LOAD OUR POINTER
        LD      A,(HL)
        LD      (VF),A          ;SAVE VISUAL FIELD VALUE
        LD      BC,258H
        ADD     HL,BC           ;BUMP POINTER
        LD      A,(HL)
        LD      (RIGHT),A       ;SAVE THE CORRECT ANSWER
        CALL    DISPLY          ;GO DISPLAY IT
        CALL    TRAPRT          ;GO WAIT FOR RT AND RESPONSE
        LD      A,(RESP)        ;PUT RESPONSE IN L REGISTER
        LD      L,A
        LD      A,(RIGHT)       ;GET CORRECT ANSWER
        SUB     L
        JP      NZ,WRONG
        CALL    HIT             ;PROVIDE "CORRECT" FEEDBACK
        JP      CONT2
WRONG:  CALL    MISS            ;"INCORRECT" FEEDBACK
CONT2:  LD      BC,2BCH         ;VALUE OF 300 DECIMAL IN BC
        LD      HL,(DATA)       ;WE'VE GOT TO RESET THE
                                ;POINTER (MAYBE)
        ADD     HL,BC
        LD      A,(RESP)
        LD      (HL),A          ;SAVE THE RESPONSE IN THE
                                ;DATA ARRAY
        LD      BC,64H          ;VALUE OF 100 DECIMAL IN BC
        ADD     HL,BC           ;BUMP POINTER
        LD      A,(RTH)
        LD      (HL),A          ;SAVE THE HIGH BYTE OF RT
        ADD     HL,BC           ;BUMP POINTER
        LD      A,(RTL)
        LD      (HL),A          ;SAVE THE LOW BYTE OF RT
        LD      A,(COUNT)
        INC     A               ;INCREMENT THE COUNTER
        LD      (COUNT),A       ;SAVE THE NEW COUNT
        SUB     65H             ;IS IT UP TO 101 YET?
        JP      Z,FINIS         ;IF SO, THIS BLOCK IS DONE
        LD      HL,(DATA)       ;IF NOT, GET DATA ARRAY
                                ;ADDRESS
        INC     HL              ;POINT TO NEXT ROW OF DATA
        LD      (DATA),HL       ;SAVE THE POINTER
        JP      BEGIN           ;GOTO BEGINNING NEXT TRIAL
```

```
FINIS:  CALL    DELAY7              ;PAUSE FOR FEEDBACK
        CALL    CLS                 ;CLEAR THE SCREEN
        RET                         ;ALL DONE, RETURN
;
;  HERE ARE ALL THE NECESSARY SUBROUTINES
;
;  THE FIRST SETS UP THE COORDINATES FOR PRESENTATION IN
;  DIFFERENT VISUAL FIELDS BASED ON THE DISPLACEMENT (IN
;  PIXELS) PASSED TO THIS ROUTINE FROM THE CALLING PROGRAM.
;
SETVIS: LD      DE,(VISANG)         ;ADJUST THE X VALUES BY
                                    ;THE OFFSET
        LD      A,(DE)
        LD      (RXLOW),A           ;SAVE LOW BYTE OF X ADDRESS
                                    ;IN RVF
        LD      A,0FFH
        LD      HL,(VISANG)
        SUB     (HL)
        SUB     06H                 ;SUBTRACT WIDTH OF LETTER
        LD      (LXLOW),A           ;SAVE LOW BYTE OF X ADDRESS
                                    ;IN LVF
        RET
;
;  HERE IS THE MAIN DISPLAY ROUTINE.  IT CALLS THE
;  COUNTDOWN, THEN PLOTS AND ERASES THE CHARACTER TARGET.
;
DISPLY: CALL    GETVIS              ;SET UP CORRECT VISUAL FIELD
        CALL    LDLET               ;LOAD THE TARGET LETTERS
        EXX                         ;SAVE THEM
        CALL    CNTDWN              ;EARLY DISPLAY
        EXX                         ;RETRIEVE THE LETTERS
        CALL    SHOWEM              ;SHOW THE WORD
        CALL    DELAY               ;EXPOSURE
        CALL    ERASE               ;CLEAR THE WORD
        RET
;
;  THIS IS THE COUNTDOWN ROUTINE.  IT BEGINS WITH A DELAY
;  (TO ALLOW THE FEEDBACK TO BE READ BY THE SUBJECT), THEN
;  CLEARS THE SCREEN AND PRESENTS THE CHARACTERS "3", "2",
;  "1", "+" AND THEN POSITIONS THE GRAPHICS CURSOR FOR THE
;  PRESENTATION OF THE TARGET CHARACTER.
;
CNTDWN: CALL    DELAY7
        CALL    CLS                 ;CLEAR SCREEN
        CALL    CENTER
        CALL    PLOTCH
        LD      B,2BH               ;KEEP A "+" ON THE SCREEN
        CALL    SEND
        CALL    DELAY7              ;DELAY FOR 7 * 100
        CALL    DELAY7              ;MILLISECONDS
        CALL    DELAYH
        CALL    DELAYH
        CALL    CENTER              ;GET TO MIDDLE OF SCREEN
```

```
        CALL    PLOTCH
        LD      B,33H           ;PUT A "3" IN B REGISTER
        CALL    SEND
        CALL    DELAY7          ;DELAY FOR 700 MILLISECONDS
        CALL    CENTER
        CALL    PLOTCH
        LD      B,32H           ;PUT A "2" IN B REGISTER
        CALL    SEND
        CALL    DELAY7
        CALL    CENTER
        CALL    PLOTCH
        LD      B,31H           ;PUT A "1" IN B REGISTER
        CALL    SEND
        CALL    DELAY7
        CALL    CENTER
        CALL    PLOTCH
        LD      B,2BH           ;PUT A "+" IN B REGISTER
        CALL    SEND
        RET
;
;  THIS ROUTINE SETS UP THE CORRECT X VALUES FROM THE
;  VISUAL FIELD
;
GETVIS: LD      A,(VF)          ;GET THE VISUAL FIELD
        SUB     4CH             ;COMPARE IT TO "L"
        JP      NZ,SETR         ;IF NOT, GO TO RVF SETUP
        LD      A,00H
        LD      (XHI),A
        LD      A,(LXLOW)
        LD      (XLO),A
        JP      CONT1
SETR:   LD      A,01H
        LD      (XHI),A
        LD      A,(RXLOW)
        LD      (XLO),A
CONT1:  RET
;
;  THIS ROUTINE LOADS THE LETTERS OF THE WORD TO BE
;  DISPLAYED IN FIVE DIFFERENT REGISTERS
;
LDLET:  LD      HL,(DATA)       ;GET POINTER
        LD      BC,64H
        ADD     HL,BC           ;BUMP IT
        LD      A,(HL)          ;GET LETTER 1
        LD      (TEMP1),A       ;SAVE IT FOR AWHILE
        ADD     HL,BC           ;BUMP IT
        LD      A,(HL)          ;GET LETTER 2
        LD      D,A
        ADD     HL,BC           ;BUMP IT
        LD      A,(HL)          ;GET LETTER 3
        LD      E,A
        ADD     HL,BC
        LD      A,(HL)          ;GET LETTER 4
```

```
        LD      (TEMP2),A          ;SAVE IT FOR AWHILE
        ADD     HL,BC
        LD      A,(HL)
        LD      L,A                ;SAVE LETTER 5
        LD      A,(TEMP2)          ;RETRIEVE LETTER 4
        LD      H,A                ;SAVE IT
        LD      A,(TEMP1)
        LD      C,A                ;SAVE LETTER 1
        RET                        ;ALL DONE
;
;  THIS ROUTINE IS LONG AND IS A BRUT FORCE METHOD OF
;  SHOWING THE LETTERS OF THE WORD TO BE DISPLAYED IN A
;  VERTICAL FORMAT.
;
SHOWEM: LD      B,84H              ;SET GCPOS COMMAND
        CALL    SEND
        LD      A,(XHI)
        LD      B,A
        CALL    SEND
        LD      A,(XLO)
        LD      B,A
        CALL    SEND
        LD      B,01H              ;ALL Y VALUES ARE KNOWN
                                   ;BEFORE HAND
        CALL    SEND
        LD      B,03H
        CALL    SEND
        CALL    PLOTCH
        LD      B,C                ;GET LETTER 1
        CALL    SEND
        LD      B,84H
        CALL    SEND
        LD      A,(XHI)
        LD      B,A
        CALL    SEND
        LD      A,(XLO)
        LD      B,A
        CALL    SEND
        LD      B,00H
        CALL    SEND
        LD      B,0F6H
        CALL    SEND
        CALL    PLOTCH
        LD      B,D                ;GET LETTER 2
        CALL    SEND
        LD      B,84H
        CALL    SEND
        LD      A,(XHI)
        LD      B,A
        CALL    SEND
        LD      A,(XLO)
        LD      B,A
        CALL    SEND
```

```
        LD      B,00H
        CALL    SEND
        LD      B,0EAH
        CALL    SEND
        CALL    PLOTCH
        LD      B,E             ;GET LETTER 3
        CALL    SEND
        LD      B,84H
        CALL    SEND
        LD      A,(XHI)
        LD      B,A
        CALL    SEND
        LD      A,(XLO)
        LD      B,A
        CALL    SEND
        LD      B,00H
        CALL    SEND
        LD      B,0DEH
        CALL    SEND
        CALL    PLOTCH
        LD      B,H             ;GET LETTER 4
        CALL    SEND
        LD      B,84H
        CALL    SEND
        LD      A,(XHI)
        LD      B,A
        CALL    SEND
        LD      A,(XLO)
        LD      B,A
        CALL    SEND
        LD      B,00H
        CALL    SEND
        LD      B,0D2H
        CALL    SEND
        CALL    PLOTCH
        LD      B,L             ;GET LETTER 5
        CALL    SEND
        RET
;
;  THIS ROUTINE LOADS THE REGISTERS WITH BLANKS AND THEN
;  ERASES THE SCREEN
;
ERASE:  LD      A,20H           ;LOAD A BLANK CHARACTER
        LD      C,A
        LD      D,A
        LD      E,A
        LD      H,A
        LD      L,A
        CALL    SHOWEM
        RET
;
;  THIS ROUTINE POSITIONS THE GRAPHICS CURSOR SO THAT THE
;  CHARACTER PLOTTED NEXT WILL BE CENTERED IN THE DISPLAY.
```

```
;
CENTER: LD      A,84H
        LD      B,A
        CALL    SEND
        LD      B,00H
        CALL    SEND
        LD      B,0FBH
        CALL    SEND
        LD      B,00H
        CALL    SEND
        LD      B,0E9H
        CALL    SEND
        RET
;
;  THIS ROUTINE TRAPS THE REACTION TIME OF THE SUBJECT AND
;  ALSO GATHERS THE RESPONSE (WHICH KEY WAS DEPRESSED) AND
;  STORES ALL THREE VALUES.
;
TRAPRT: CALL    CLRPRT
        LD      DE,00H
LOOP:   CALL    DELAY1          ;DELAY ONE MILLISECOND
        IN      A,(KEYSTA)
        AND     02H             ;CHECK KEYBOARD STATUS BIT
        JP      NZ,CONT4        ;JUMP IF READY TO READ
        INC     DE
        JP      LOOP            ;NOT A RESPONSE YET
CONT4:  IN      A,(KEYIN)       ;GET THE RESPONSE
        AND     7FH             ;STRIP HIGH BIT
        CALL    CLRPRT          ;RESET STATUS
        LD      (RESP),A
        LD      A,D
        LD      (RTH),A
        LD      A,E
        LD      (RTL),A
        RET
;
;  THIS ROUTINE CLEARS BIT TWO OF THE PARALLEL STATUS PORT.
;
CLRPRT: PUSH    AF              ;SAVE REGISTERS
        LD      A,30H
        OUT     (KEYSTA),A      ;RESET STATUS PORT
        POP     AF              ;RESTORE REGISTERS
        RET
;
;  THIS ROUTINE DELAYS FOR ONE MILLISECOND
;
DELAY1: LD      BC,0A5H         ;LOAD A LOOP COUNT
NEXT1:  DEC     BC
        LD      A,B
        OR      C
        JP      NZ,NEXT1        ;LOOP IF NON-ZERO
        RET
;
```

```
;  THIS ROUTINE DELAYS FOR WHATEVER EXPOSURE DURATION WAS
;  PASSED TO IT
;
DELAY:  LD      A,(EXPOHI)
        LD      D,A
        LD      A,(EXPOLO)
        LD      E,A
NEXT6:  LD      BC,0A5H          ;LOAD FOR 1 MILLISEC DELAY
NEXT7:  DEC     BC
        LD      A,B
        OR      C
        JP      NZ,NEXT7
        DEC     DE
        LD      A,D
        OR      E
        JP      NZ,NEXT6
        RET
;
;  THIS ROUTINE DELAYS FOR 100 MILLISECONDS
;
DELAYH: LD      DE,64H           ;LOAD COUNTER WITH 100
NEXT3:  LD      BC,0A5H
NEXT2:  DEC     BC
        LD      A,B
        OR      C
        JP      NZ,NEXT2
        DEC     DE
        LD      A,D
        OR      E
        JP      NZ,NEXT3         ;100 MILLISEC COUNTER ZERO?
        RET
;
;  THIS ROUTINE DELAYS FOR 700 MILLISECONDS
;
DELAY7: LD      DE,2BCH          ;LOAD COUNTER WITH 700
NEXT4:  LD      BC,0A5H
NEXT5:  DEC     BC
        LD      A,B
        OR      C
        JP      NZ,NEXT5
        DEC     DE
        LD      A,D
        OR      E
        JP      NZ,NEXT4
        RET
;
;  THIS ROUTINE PROVIDES FEEDBACK, IT SENDS "CORRECT" TO THE
;  SCREEN, CENTERED ON THE SCREEN
;
HIT:    LD      A,84H
        LD      B,A
        CALL    SEND
        LD      B,00H
```

```
        CALL    SEND
        LD      B,0EAH
        CALL    SEND
        LD      B,00H
        CALL    SEND
        LD      B,0E9H
        CALL    SEND
        CALL    REST2
        RET
;
;   THIS ROUTINE PROVIDES FEEDBACK AS WELL, IT CENTERS
;   "INCORRECT" ON THE SCREEN.
;
MISS:   LD      A,84H
        LD      B,A
        CALL    SEND
        LD      B,00H
        CALL    SEND
        LD      B,0E4H
        CALL    SEND
        LD      B,00H
        CALL    SEND
        LD      B,0E9H
        CALL    SEND
        CALL    PLOTCH
        LD      B,49H
        CALL    SEND
        CALL    PLOTCH
        LD      B,4EH
        CALL    SEND
REST2:  CALL    PLOTCH
        LD      B,43H
        CALL    SEND
        CALL    PLOTCH
        LD      B,0CFH
        CALL    SEND
        CALL    PLOTCH
        LD      B,52H
        CALL    SEND
        CALL    PLOTCH
        LD      B,52H
        CALL    SEND
        CALL    PLOTCH
        LD      B,45H
        CALL    SEND
        CALL    PLOTCH
        LD      B,43H
        CALL    SEND
        CALL    PLOTCH
        LD      B,54H
        CALL    SEND
        RET
;
```

```
;  THIS ROUTINE CLEARS THE SCREEN USING THE CLEAR SCREEN
;  COMMAND OF THE MICROANGELO.
;
CLS:    LD      A,88H
        LD      B,A
        CALL    SEND
        RET
;
;  THIS ROUTINE SENDS THE COMMAND TO PLOT A GRAPHIC
;  CHARACTER AND THEN FALLS INTO THE SEND COMMAND, WHICH
;  MOVES THE BYTE IN THE B REGISTER OVER TO THE MICROANGELO.
;
PLOTCH: LD      A,98H
        LD      B,A
SEND:   IN      A,(MASTAT)
        AND     01H
        JP      NZ,SEND
        LD      A,B
        OUT     (MAOUT),A
        RET
;
;  HERE ARE THE DATA LOCATIONS USED IN THE PROGRAM.
;
VISANG: DS      2
DATA:   DS      2
COUNT:  DS      1
VF:     DS      1
TEMP1:  DS      1
TEMP2:  DS      1
XHI:    DS      1
XLO:    DS      1
RIGHT:  DS      1
LXLOW:  DS      1
RXLOW:  DS      1
RESP:   DS      1
RTH:    DS      1
RTL:    DS      1
EXPOHI: DS      1
EXPOLO: DS      1
;
        END
```

The rest of the code for both the first and second experiments may be obtained from the author at:

Department of Computer Science
SUNY College at Oswego
Oswego, NY 13126

APPENDIX B

STIMULI FOR EXPERIMENTS 1 AND 2

STIMULI USED IN EXPERIMENT 1

NOUNS

word	nonword
AGENT	AZENT
BENCH	BEDCH
BIBLE	BIBRE
BLOOD	BLOOG
BRIDE	BLIDE
CHAIR	CHAID
CHEST	CLEST
CHILD	CHILF
CRIME	CRITE
DRAMA	FRAMA
EARTH	EAGTH
ENEMY	ELEMY
EVENT	ELENT
FLESH	CLESH
FLOOR	FLOOB
GRAIN	[1]
GRASS	GRAGS
GUEST	HUEST
HEART	HEANT
HORSE	HOLSE
HOTEL	SOTEL
MAGIC	MALIC
MAJOR	MAKOR
MONEY	RONEY
MONTH	FONTH
MOVIE	[1]
MUSIC	MUPIC
NIGHT	DIGHT
NOISE	NOIDE
OCEAN	OFEAN
OPERA	OKERA
PEACE	PEABE
PIANO	FIANO
PIECE	PIENE
PROOF	PROOG
QUEEN	QUEED
QUIET	QUIED
RIVER	RIBER
SCENE	SHENE
SHEET	SHEED
SHIRT	[1]

SNAKE	SNACE
STORY	SKORY
SUGAR	SUGAF
TABLE	TABNE
THING	CHING
TITLE	TITKE
VERSE	[1]
WIDOW	[1]
WOMAN	WOFAN

VERBS

word	nonword
ADMIT	ADLIT
AGREE	ABREE
ALLOW	ADLOW
ARGUE	ARDUE
ARISE	ARIGE
AVOID	AVOIK
BEGIN	BEBIN
BRING	BRINP
BUILD	BUILK
CARRY	CABRY
CATCH	GATCH
CHOSE	SHOSE
CLOSE	CROSE
DRAFT	[1]
DRIVE	CRIVE
ENJOY	ENFOY
ENTER	ENKER
GROWN	PROWN
GUESS	GUESH
HEARD	MEARD
HURRY	HUKRY
LAUGH	LAUSH
LEARN	JEARN
LEAVE	LEAGE
PAUSE	[1]
PROVE	PLOVE
RAISE	RAIME
REACH	FEACH
REFER	[1]
SERVE	SEKVE
SHARE	SHAZE
SHEAR	SKEAR
SHOOK	SHOOB
SHOOT	[1]
SHOWN	SHOLN
SPEAK	SKEAK
SPEND	SHEND
SPENT	SPEVT
START	STARD

STOOD	STOOB
STRIP	SHRIP
TAKEN	HAKEN
TASTE	TASBE
TEACH	TEACT
THANK	TWANK
THINK	THENK
THROW	[1]
WRITE	PRITE
WROTE	WROCE
YIELD	YIELS

STIMULI USED IN EXPERIMENT 2

NOUNS

word	nonword	frequency
AGENT	AGERT	44
ALBUM	ADBUM	6
ANGEL	ANGEM	18
ANVIL	ANRIL	1
APPLE	APTLE	9
ATTIC	ATTIB	16
BANJO	BANRO	2
BENCH	BETCH	35
BONGO	BUNGO	1
BRICK	BRIEK	18
BROOM	BROAM	2
BROTH	[2]	3
CAMEL	CEMEL	1
CANDY	CASDY	16
CHAIR	CHAIT	66
CIGAR	LIGAR	10
EARTH	EARCH	150
ENEMY	EBEMY	88
FABLE	FARLE	2
FLASK	FLASN	5
FLESH	FLOSH	52
FLOOR	BLOOR	158
GRAIN	GRAIC	27
GRAVY	TRAVY	4
HOTEL	HETEL	126
JELLY	MELLY	3
JUROR	JURON	4
LILAC	LILOC	4
LINGO	[2]	3
LIVER	ZIVER	16
MAGIC	HAGIC	37
MELON	BELON	1
MOTTO	MOTLO	4
MOUSE	COUSE	10
NIGHT	NOGHT	411

NOISE	DOISE	37
ONION	OTION	15
PHOTO	PHOTH	5
PIECE	PLECE	129
RIVER	NIVER	165
RULER	RALER	3
SAINT	LAINT	16
SCARF	SCART	4
SHIRT	SHIRL	27
SIREN	SITEN	1
SLANG	SLENG	2
SNAKE	SNATE	44
SPINE	SPANE	6
STOVE	SNOVE	15
SUGAR	SUMAR	34
SWINE	SWONE	3
SWORD	SWORL	7
TABLE	RABLE	198
TIGER	TIGEM	7
TITLE	TATLE	77
TOWEL	TAWEL	6
WHEAT	WHOAT	9
WITCH	WISCH	5
WOMAN	WOVAN	224
ZEBRA	MEBRA	1

VERBS

word	nonword	frequency
ABIDE	AMIDE	7
ADMIT	ASMIT	37
ADOPT	ADOUT	13
ARGUE	ARLUE	29
BLESS	BLOSS	9
BRING	BRONG	158
BROIL	CROIL	2
BUILD	RUILD	86
CARVE	DARVE	3
CATCH	CANCH	43
CHASE	CLASE	18
CINCH	TINCH	3
CLOSE	CLOSM	234
CRAVE	CLAVE	2
CRAWL	FRAWL	11
DEFER	DEBER	1
DRAFT	DRATT	24
DRIVE	DRINE	105
EJECT	EJOCT	1
ELECT	ELECK	8
ENTER	ONTER	78
EVADE	[3]	1
EVOKE	EVOME	6

FETCH	GETCH	6
GRASP	GEASP	17
GREET	GLEET	7
GROPE	GLOPE	1
IMPLY	IMPAY	12
INCUR	ONCUR	5
KNEEL	KLEEL	5
LAUGH	LAUTH	28
MUNCH	MURCH	1
PROWL	PROWN	2
RAISE	RAIME	52
REACH	REATH	106
REACT	REANT	15
SCOUR	SCOUM	1
SCRUB	SCRUT	9
SCUFF	SCUFT	1
SHAVE	SHABE	6
SNIFF	SNIEF	2
SOLVE	NOLVE	20
SPEAK	SPEAT	110
SPURT	SPUNT	2
START	STURT	154
STING	STONG	5
SWEEP	SWESP	15
SWIPE	SKIPE	2
SWOOP	SWOOL	2
TASTE	TASHE	59
TEACH	TRACH	41
THANK	THONK	36
THINK	THINT	433
THROW	THOOW	42
TWIST	SWIST	18
WHACK	WHACT	1
WREST	WRESS	1
WRITE	WRITH	106
YEARN	YEALN	1
YODEL	YOTEL	1

MIXED WORDS

word	nonword	frequency
AUDIT	AUDIL	4
AWARD	AWAMD	46
BLOCK	SLOCK	66
BLUFF	BLAFF	8
BLUSH	BLUGH	2
CHILL	THILL	14
CLOAK	PLOAK	3
COAST	CLAST	61
COUGH	GOUGH	7
COVER	CAVER	88
CRANK	CRALK	1

CREEP	CLEEP	10
CROWD	CROND	53
CURSE	CURSH	11
DANCE	DANCH	90
DRAIN	DROIN	18
EXILE	[2]	4
FLAKE	FLABE	1
FLARE	FLABE	3
GRAPH	[3]	17
GRUNT	GRUND	2
GUARD	GUALD	48
HATCH	DATCH	5
JUDGE	MUDGE	77
LADLE	LAGLE	1
MINCE	MILCE	1
MOUND	MOUNG	11
ORDER	ERDER	376
PAINT	PLINT	37
PATCH	POTCH	13
PLANT	PLUNT	125
PROBE	PROBT	6
PUNCH	SUNCH	5
RELAY	REKAY	2
SCALE	SPALE	60
SCALP	SNALP	4
SHRUG	THRUG	2
SLICE	PLICE	13
SPEED	SMEED	88
SPIKE	SNIKE	2
SPOUT	SLOUT	1
STACK	SPACK	9
STALL	STELL	18
STAMP	STEMP	8
STICK	SNICK	39
STOCK	STECK	138
STRAY	SHRAY	12
STRUT	STRUB	3
TEASE	TEASH	6
TRAIN	TRALN	82
TRAMP	THAMP	1
TRICK	TWICK	15
VALVE	HALVE	200
VISIT	VISIM	109
WAGER	TAGER	3
WATCH	WANCH	81
WEAVE	MEAVE	4
WHOOP	WHOOK	1
WORRY	WORLY	55
WRECK	WROCK	8

[1] no nonword was created for this item
[2] word was repeated, item treated as missing
[3] two letters changed, item treated as missing

APPENDIX C

ADJUSTED REACTION TIME PLOTS

Figures 14 and 15 show raw RT plotted versus the presentation sequence number. One can see variable performance over time, with no apparent relationship evident between correct responses and incorrect responses. To more closely examine the RT values over time, adjusted reaction time plots were drawn. An adjusted RT for any trial is calculated by summing the lagged RT differences, and anchoring the value to the RT of the first presentation. In effect,

$$\text{adjusted } RT_{i+1} = RT_1 + \sum \frac{RT_{i+1} - RT_i}{seq_{i+1} - seq_i}$$

where seq is the sequence number, or number of the trial (1 through 10,800). The plots are then smoothed using 4(3RSR)2H twice (repeated smoothing by medians of 3, followed by end-point smoothing of peaks and valleys, repeated 4 times, followed by hanning twice, followed by twicing. Hanning calculates moving averages. Twicing is the process of smoothing, computing the residuals from the smooth, smoothing the residuals and adding the two smoothed series together. See Tukey (1977) for details). Figures 16 and 17 are the smoothed adjusted RT plots for the data in Figures 14 and 15, respectively. Figure 16 has further split out

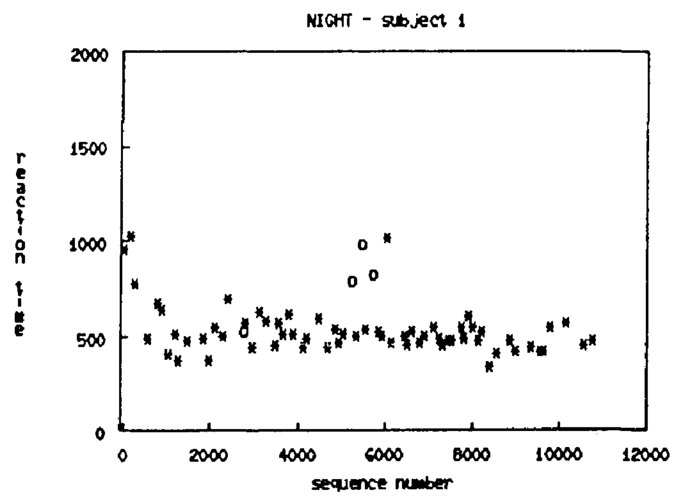


Figure 14. Reaction Time by Sequence Number for "NIGHT", Subject 1

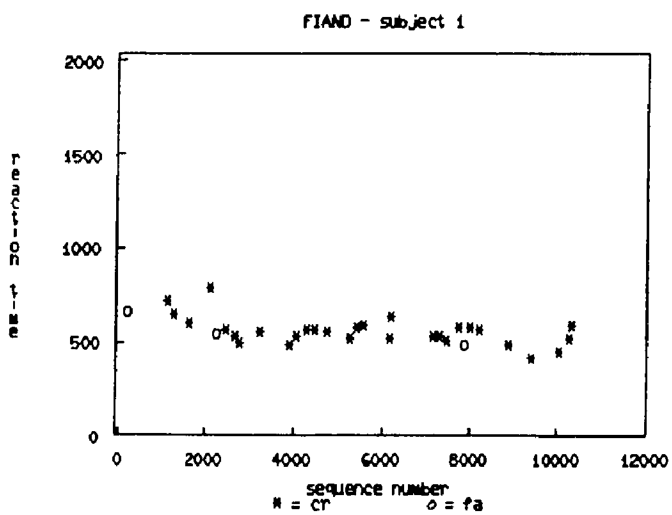


Figure 15. Reaction Time by Sequence Number for "FIANO", Subject 1

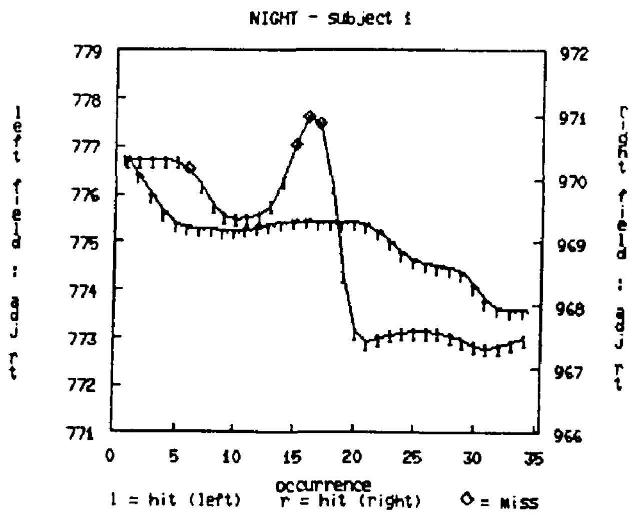


Figure 16. Adjusted RT by Occurrence and VF for "NIGHT", Subject 1

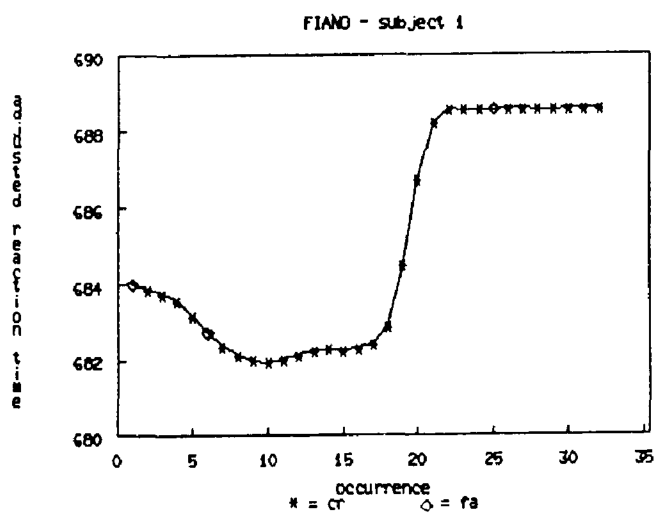


Figure 17. Adjusted RT by Occurrence for "FIANO", Subject 1

LVF-RH and RVF-LH presentations, which was not done in Figure 14. Note that the adjusted RT values for left and right visual fields are differently scaled. This is a result of anchoring to the first RT. The complete set of adjusted RT plots is available from the author (see Appendix A for address).

There are several ways of organizing the adjusted RT curves. The most obvious is to cluster them according to slope, in general groupings of negative slope, positive slope and zero slope (corresponding to learning, 'negative' learning and no learning). Looking at non-word items, divided into word class categories and further subdivided into LVF-RH, RVF-LH and BothVF presented items, a curious circumstance appears. For subject one, as the amount of learning decreases, so do the number of errors (false alarms) for RVF-LH items. For LVF-RH items, the opposite is true, as learning decreases, the number of errors increases. Comparing the curves for FLOOB and SUGAF (both LVF-RH items) to HEANT and BEDCH illustrates the point. These four items have the greatest error rates for subject one among the noun-derived nonwords. These effects seem to cancel out when looking at nonword items presented to both visual fields, where there is no relationship between number of errors and amount of learning. The items GRAGS, SHEED, BLIDE show the highest number of errors. All three show a general learning effect, although it is a learning curve that shows considerable confusion, with numerous local maxima.

It is worth describing the implications of this in detail. For subject one, for nonword items derived from high frequency nouns presented to the right hemisphere, the inability to recognize an item as a nonword is related to increasingly slower decision making. For nonword items presented to the left hemisphere, decision making speeds up, but the decision remains in error. The item is recognized as familiar (increasingly speeded responses), but the item is not recognized as a nonword. This is in spite of the feedback given the subject. Note that while overall the relation between learning and error rate is nil for nonword items presented to both hemispheres, the three items with extremely high error rates all show learning, faster responses over time.

These effects are not present for nonword items derived from verbs. For items presented to the LVF-RH, RVF-LH or BothVF, there is a slight negative correlation - as the number of errors increases, the degree of learning decreases. This is also true for word items presented to either visual field.

Subject two was significantly slower in responding, made fewer errors overall, and the adjusted RT plots show little pattern or consistency. BIBRE, presented to the LVF-RH, shows significantly more errors than any other item presented to the LVF-RH, and shows a positive slope. BEDCH, presented to the RVF-LH, shows significantly more errors than any other item presented to the RVF-LH, and shows a learning effect. BLIDE and SHEED again show the highest number of errors for items presented to both visual fields.

Overall, though, no consistent relationship between learning curves, number or position of errors, or visual field was found. It is disappointing that little was gained by examining the adjusted RT plots for individual items. The technique shows promise in describing small differences in learning over time.