DOCUMENT RESUME

ED 268 511 CS 008 417

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| AUTHOR | Massaro, Dominic W.; And Others |
| TITLE | Frequency, Orthographic Regularity, and Lexical Status in Letter and Word Perception. Technical Report No. 550. |
| INSTITUTION | Wisconsin Univ., Madison. Research and Development Center for Individualized Schooling. |
| SPONS AGENCY | National Inst. of Education (ED), Washington, DC. |
| PUB DATE | Aug 80 |
| GRANT | OB-NIE-G-80-0117 |
| NOTE | 117p.; A report from the Project on Studies in Language: Reading and Communication. |
| PUB TYPE | Reports - Research/Technical (143) |
| EDRS PRICE | MF01/PC05 Plus Postage. |
| DESCRIPTORS | *Cognitive Processes; English; Higher Education; *Letters (Alphabet); *Orthographic Symbols; *Reading Research; Spelling; Visual Learning; *Word Frequency; *Word Recognition; Word Study Skills |
| IDENTIFIERS | *Orthographic Structure |


ABSTRACT

A study assessed the role of orthographic structure in college students' perceptual recognition and judgment of letter strings. Lexical status, word frequency, bigram frequency, log bigram frequency, and regularity of letter sequencing were orthogonally varied across a series of experiments. Six-letter words and their anagrams were used as test stimuli in a target-search task. Results showed that words were recognized better than their corresponding equally well-structured anagrams, but that word frequency had little effect. Orthographically regular anagrams were recognized better than irregular anagrams, whereas log bigram frequency did not have an effect. In contrast, post hoc correlations revealed that log bigram frequency did correlate significantly with individual item performance. In a final experiment, subjects judged which of a pair of letter strings most resembled English in terms of either the frequency or the regularity of letter sequences. Findings revealed an influence of essentially the same dimensions of orthographic structure as that revealed by the perceptual recognition task. The overall results provided evidence for lexical status, regularity of letter sequencing, and frequency of letter sequencing as important dimensions in the psychologically real description of orthographic structure. (Author/FL)

Technical Report No. 550

# FREQUENCY, ORT[illegible]PHIC REGULARITY, AND LEXICAL S[illegible]S IN LETTER AND WORD PERCEPTION

by

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Report from the Project on
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August 1980

Published by the Wisconsin Research and Development Center for Individualized Schooling. The project presented or reported herein was performed pursuant to a grant from the National Institute of Education, Department of Health, Education, and Welfare. However, the opinions expressed herein do not necessarily reflect the position or policy of the National Institute of Education, and no official endorsement by the National Institute of Education should be inferred.

Center Grant No. OB-NIE-G-80-0117

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- developing and demonstrating improved instructional strategies, processes, and materials for students, teachers, and school administrators
- providing assistance to educators which helps transfer the outcomes of research and development to improved practice in local schools and teacher education institutions

The Wisconsin Research and Development Center is supported with funds from the National Institute of Education and the University of Wisconsin.

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Abstract

The present research assessed the role of orthographic structure in the perceptual recognition and the judgment of letter strings. Lexical status, word frequency, bigram frequency, log bigram frequency, and regularity of letter sequencing were orthogonally varied across a series of experiments. Six-letter words and their anagrams were used as test stimuli in a target-search task. Words were recognized better than their corresponding equally well-structured anagrams but word frequency had little effect. Orthographically regular anagrams were recognized better than irregular anagrams whereas log bigram frequency did not have an effect. In contrast, post hoc correlations revealed that log bigram frequency did correlate significantly with individual item performance. In a final experiment, subjects judged which of a pair of letter strings most resembled English in terms of either the frequency or the regularity of letter sequences. The results revealed an influence of essentially the same dimensions of orthographic structure as was revealed by the perceptual recognition task. The results provide evidence for lexical status, regularity of lettter sequencing, and frequency of letter sequencing as important dimensions in the psychologically - real description of orthographic structure.

Orthographic structure and visual processing of letters and words.

It is widely acknowledged that the reader contributes as much or more to reading than does the "information" on the printed page. One compelling issue in reading research is how the reader's higher-order knowledge of the language interacts with lower-level perceptual analyses during reading. The specific question addressed in the present paper is how the reader's knowledge about orthographic structure is combined with the information derived from visual featural analysis in letter and word recognition. Orthographic structure refers to the spelling constraints in a written language. Visual featural analysis refers to the evaluation of component properties of letters leading to letter and word recognition. Given the considerable amount of predictability in English writing, we ask how the reader utilizes this orthographic structure in word recognition.

Evaluation of the contributions of visual features and orthographic structure to word recognition can be facilitated by a detailed description of the processes involved in reading. The description we use is part of a more general model of language processing model (Massaro, 1975, 1978, 1979a; Massaro, Taylor, Venezky, Jastrzembski & Lucas, 1980). According to the model, reading can be viewed as a sequence of processing stages. Figure 1 presents a schematic representation of the stages of processing; at each stage of processing, memory and process components are

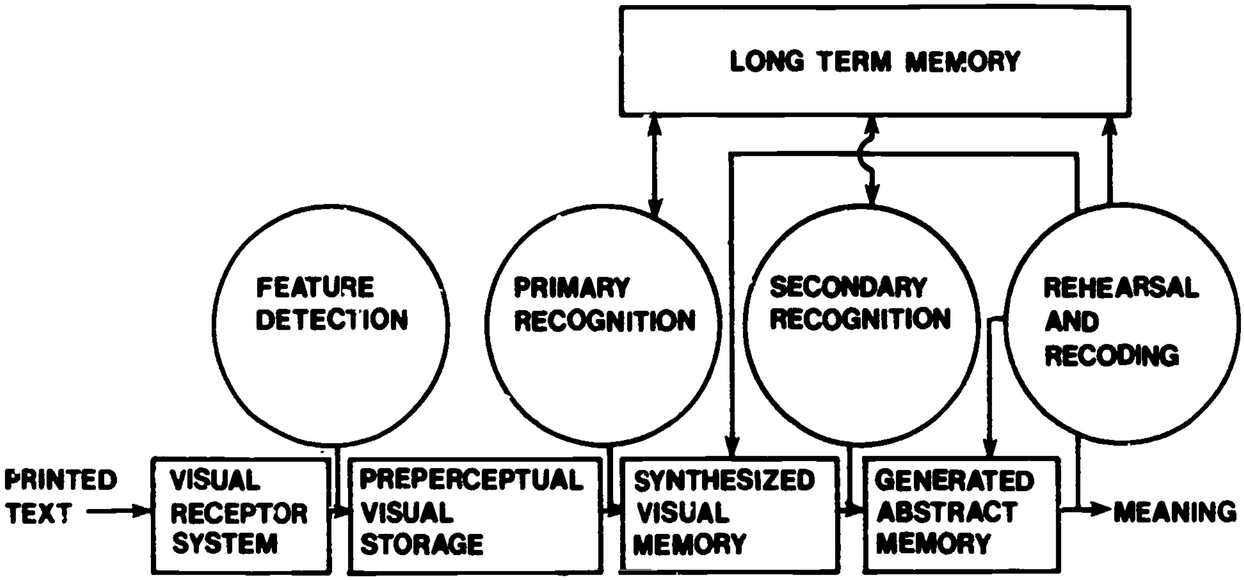



Figure 1 A stage model of reading printed text.

represented. Each memory component (indicated by a rectangle) corresponds to the information available at a particular stage of processing. Each process component (indicated by a circle) corresponds to the operations applied to the information held by the memory component. The memory components are temporary storages except for long-term memory which is relatively permanent. It is assumed that long-term memory supplements the information at some of the processing stages.

During reading, the light pattern reflected from a display of letters is transduced by the visual receptors as the feature detection process detects and transmits visual features to preperceptual visual storage (see Figure 1). As visual features enter in preperceptual visual storage, the primary recognition process attempts to transform these isolated features into a sequence of letters and spaces in synthesized visual memory. To do this, the primary recognition process can utilize information held in long-term memory. For the accomplished reader this includes a list of features for each letter of the alphabet along with information about the orthographic structure of the language. Accordingly, the primary recognition process uses both the visual features in preperceptual storage and knowledge of orthographic structure in long-term memory during the synthesis of letter strings.

The primary recognition process operates on a number of letters simultaneously (in parallel). The visual features detected at each spatial location of the letter string define a set of possible letters for that position. The primary recognition process chooses from this set of candidates the letter alternative which has the best correspondence in terms of visual features. However, the selection of a letter can be facilitated by the reader's knowledge of orthographic structure. The primary recognition process therefore, attempts to utilize both the featural information in preperceptual storage and knowledge about the structure of letter strings in long-term memory. We assume that orthographic structure is utilized in the following manner: Upon presentation of a letter string, the primary recognition process begins integrating and synthesizing featural information passed on by feature detection to preperceptual visual storage. Featural information is resolved at different rates and there is some evidence that gross features are available before the more detailed features (Massaro & Schmuller, 1975). The primary recognition process is faced with a succession of partial information states. These partial information states are supplemented with knowledge about orthographic structure. Assume, for example, an initial _th_ has been perceived in a letter string, and the features available for the next letter eliminate all alternatives except _c_ and _e_. The primary recognition process would synthesize _e_ without waiting for further visual information, since initial _thc_ is not acceptable, while initial _the_ is.

The primary recognition process transmits a sequence of recognized letters to synthesized visual memory. Figure 1 shows how the secondary recognition process transforms this synthesized visual percept into a meaningful form in generated abstract memory. We assume secondary recognition attempts to close off the letter string into a word. The secondary recognition process makes this transformation by finding the best match between the letter string and a word in the lexicon in long-term memory. Each word in the lexicon contains both perceptual and conceptual codes. The word which is recognized is the one whose perceptual code gives the best match and whose conceptual code is most appropriate in that particular context. Knowledge of orthographic structure can also contribute to secondary recognition; word recognition can occur without complete recognition of all of the component letters. Given the letters bea and the viable alternatives l and t in final position, only t makes a word, and therefore word identification (lexical access) can be achieved (Massaro, Note 1).

Our goals in the present series of experiments are to provide a better understanding of the primary and secondary recognition process and to evaluate which aspect of orthographic structure the reader knows and uses. To assess how readers utilize knowledge about the structure of written language, it is necessary to state various descriptions of this structure and then to determine how well these descriptions capture reading performance. Venezky and Massaro (1979), Massaro, Venezky, & Taylor (1979) and Massaro et al. (1930) have distinguished between two broad categories of orthographic structure: statistical redundancy and rule-governed regularity. The first category includes all descriptions derived solely from the frequency of letters and letter sequences in written texts. The second category includes all descriptions derived from the phonological constraints in English and scribal conventions for the sequences of letters in words. Since a change in one category would not affect the other, the two categories were viewed as nonoverlapping. The task then was to first decide which general category seemed to reflect the manner in which reader's store knowledge of orthographic structure and second, to determine precisely which specific description within that catrgory has the most psychological reality.

Massaro et al. (1979a, 1980) contrasted a specific statistical-redundancy description with a specific rule-governed description by comparing letter strings that varied orthogonally with respect to these descriptions. The statistical redundancy measure was summed token single-letter frequency. The rule-governed regularity measure was a preliminary set of rules similar to those presented in Table 2 of the present paper. Letter strings were selected which represented the four combinations formed by a factorial arrangement of high and low frequency and regular or irregular. In a series of experiments utilizing a target-search task, subjects were asked to indicate whether a target letter was present in these letter strings. Both accuracy and reaction-time measures indicated psychological reality for both the frequency and the regularity description of orthographic structure.

Massaro et al. (1980) formalized the language processing model to provide a quantitative description of the facilitative effect of orthographic structure on task accuracy. The basic assumption of the model is that knowledge of orthographic structure contributes an independent source of information about the letter string. By an independent source of information, we mean that knowledge of orthographic structure does not modify or direct the feature detection process. Rather, information about visual features and orthographic structure accumulates from sources that do not interact. Since information about structure adds to featural information, fewer visual features are necessary to resolve well-structured than poorly-structured strings. The model was applied to the target-search task by formalizing a decision algorithm assumed to be used by the subject when faced with partial information. The model provided a good quantitative description of the accuracy results. The parameters of the model were psychologically meaningful and the parameter values corresponding to the number of letters seen in the test string provided a quantitative measure of the contribution of orthographic structure. According to the model, readers were able to recognize two additional letters in brief presentations of well-structured strings compared to poorly-structured strings. This is a substantial effect considering that two letters represent one-third of the six-letter test string. These results indicate that we had developed good initial approximations of both a description of orthographic structure and the means by which structure and visual features combine during word recognition. This bolstered our hope that a precise description of orthographic structure can eventually be determined and that a thorough understanding of the word recognition processes in reading can eventually be obtained.

Massaro et al. (1980) also conducted a series of overt judgment experiments to assess which descriptions of orthographic structure are consciously available. We asked whether subjects could descriminate among the items on the basis of rule-governed regularity or on the basis of statistical redundancy. Subjects were presented pairs of letter strings and asked to choose the member of each pair which most resembled written English. The instructions emphasized either a regularity or a statistical-redundancy criterion. Subjects' judgments appeared to be more accurately described by rule-governed regularity than by statistical redundancy. In this way, the results from the overt judgment task paralleled the results from the target-search task. Evidently, readers not only use their knowledge of orthographic structure during the word recognition process, but also are aware of this knowledge and can use it in tasks requiring decisions after the word recognition processes have been completed. As suggested by the model, orthographic structure appears to exert an influence on several stages of language processing (Massaro, 1980).

The factorial design of the Massaro et al. (1980) experiments contrasted just one measure of rule-governed regularity with one measure of statistical redundancy. Therefore, a large number of post hoc correlational analyses was conducted to evaluate a wide range of measures of orthographic structure. This was a first step towards refining our initial measures of orthographic structure. Through these correlations, it might be possible to determine the necessary refinements to reach our goal of a psychologically real description of orthographic structure. The dependent measure was the performance on each of 200 test items. Position-sensitive summed log bigram frequency provided the best statistical-redundancy description of performance on the individual items. Furthermore, an improved rule-based regularity measure also provided a very good description. However, the regularity measure correlated very highly with the best frequency-based measure. For this reason, it was not possible in these experiments to make a definitive choice between rule-governed and statistical-redundancy descriptions of structure.

Since Massaro et al. (1980) were not successful in choosing between rule-governed regularity and statistical redundancy descriptions, the next step is to refine our measures of structure in a further attempt to select a single measure of structure. Given the best statistical-redundancy measure, it is possible to develop a new set of test items to contrast this measure with an improved rule-governed regularity measure. We follow this logic in the present studies by factorially contrasting bigram frequency and regularity measures in target search and overt judgment tasks. Although bigram frequency and regularity are highly correlated, a design involving orthogonal contrasts might be sufficient to distinguish between them. As with the previous experiments (Massaro et al. 1980), it again will be necessary to examine post hoc correlations to determine whether some other measure might provide even a better description. By refining and repeatedly testing measures of structure, we hope to arrive at a single description that best reflects the reader's knowledge of orthographic structure.

## Experiments 1 and 2

### Method

*Subjects*. Nine subjects were used in the first experiment and eleven were used in the second. All were Introductory Psychology student volunteers who received credit toward their course grade for participating. Additionally, they were all native English speakers, right-handed, had normal or corrected to normal vison, and had not participated in any of the other experiments.

*Stimuli and apparatus*. A sample of high-frequency words was obtained from a list of all six-letter words from Kucera and Francis (1967), subject to the constraints that the words had a frequency greater than or equal to 50, were not proper nouns, and did not have repeated letters. A similar list of words with a frequency of exactly three was used to obtain low-frequency words. For each word in these two lists, all possible 720 anagrams were generated and each of their summed-positional bigram frequencies was calculated. The bigram frequencies were based on counts given by Massaro et al. (1980) which were derived from the Kucera and Francis (1967) word list. Forty high-frequency and 40 low-frequency words were selected along with four anagrams of each word. The anagrams were selected so that they formed a factorial arrangement of high and low summed-positional bigram frequency and of being orthographically regular and irregular. Orthographic regularity was manipulated in the same manner as in previous experiments (Massaro et al., 1979, 1980). The rules for choosing

Table 1

The Rules for Choosing Regular and Irregular Letter Str

Letter strings were regarded as regular if they were phonologically legal and contained common vowel and consonant spellings. A letter string was regarded as orthographically irregular if it contained at least one of the following spellings.

a. phonologically illegal initial or final cluster (e.g., rlhued or eigopn)

b. orthographically illegal spelling for an initial final consonant or consonant cluster (e.g., xeoich or tmoreh)

c. an illegal vowel spelling (e.g., caeinm)

d. a phonologically illegal medial cluster (e.g., ilrmed) regular and irregular strings are given in Table 1. Some examples of the words and their respective anagrams are presented in Figure 2. Number and person have high word frequencies while hurdle and pigeon have low frequencies. The letter string rumben is a regular-high anagram of the word number, and helrud is a regular-low anagram of hurdle. The number in each cell gives the average summed-positional bigram frequency for the items of that class. For example, the irregular-high anagrams of high frequency words have an average count of 5738.

Twenty arbitrarily chosen high-frequency words and their anagrams as well as 20 low-frequency words and their anagrams were selected as stimuli for the first experiment. The remaining 20 high- and 20 low-frequency anagrams were used with new subjects in the second experiment. The letter strings for the two experiments are presented in Appendices 1 and 2.

The visual displays were generated by a DEC LSI-11 computer under software control and presented on Tektronix Monitor 604 oscilloscope (Taylor, Klitzke, & Massaro, 1978a, 1978b). These monitors employ a P31 phosphor which decays to .1% of stimulated luminance within 32 msec of stimulus offset. The alphabet consisted of lower-case nonserfied letters resembling the type font Univers 55. For an observer seated comfortably at an experimental station, the six-letter displays subtended about 1.9 degrees of visual angle horizontally and the distance from the top of an

| Orthographic Regularity | | Words | Summed Positional Bigram Frequency: High | Summed Positional Bigram Frequency: Low |
|---|---|---|---|---|
| | | number person (6060) / hurdle pigeon (4468) | | |
| | Regular | | rumben preson (5624) / hulder gopine (4861) | runemb roneps (1415) / helrud ginope (1106) |
| | Irregular | | bemrnu npsore (5738) / rlhued eiopng (4920) | brnemu pnseor (1424) / ldeurh eigopn (1113) |

Figure 2. Example of the test words and their corresponding anagrams from Experiments 1 and 2. Within each of the five squares, the top two items correspond to high word frequency and the bottom two items correspond to low word frequency. The number in each of the ten cells represents the summed positional linear bigram frequency.

ascender to the bottom of a descender was about .4 degree. Up to four subjects could be tested in parallel in separate rooms.

Procedure. A trial (see Figure 3) began with the presentation of a 250 msec fixation point. The fixation point was replaced by a test letter string, i.e., a word or an anagram, for a duration of 10-39 msec. The duration on a particular trial for each subject was determined by his or her accuracy. The duration was adjusted every 20 trials by a modified version of the PEST algorithm (Taylor & Creelman, 1967) in order to keep the subject's average accuracy at about 75%. A masking stimulus followed the onset of the test string after a 70 msec interval. Therefore, the blank interval between the test stimulus and the masking stimulus was (70-*t*) msec, where *t* was the duration of the target string. The masking stimulus was composed of six nonsense letters. Each nonsense letter changed from trial to trial and was composed of a montage of randomly-selected features of the test letters. The feature density of a nonsense letter was equal to that of the letter *g*. The size of the nonsense letters was equivalent to that of the test string. The duration of the mask was adjusted along with the duration of the test string. The mask remained on the screen for (40-*t*) msec, giving a range of durations of 1-30 msec. The mask was followed by another blank interval and then the target letter. The second blank interval lasted

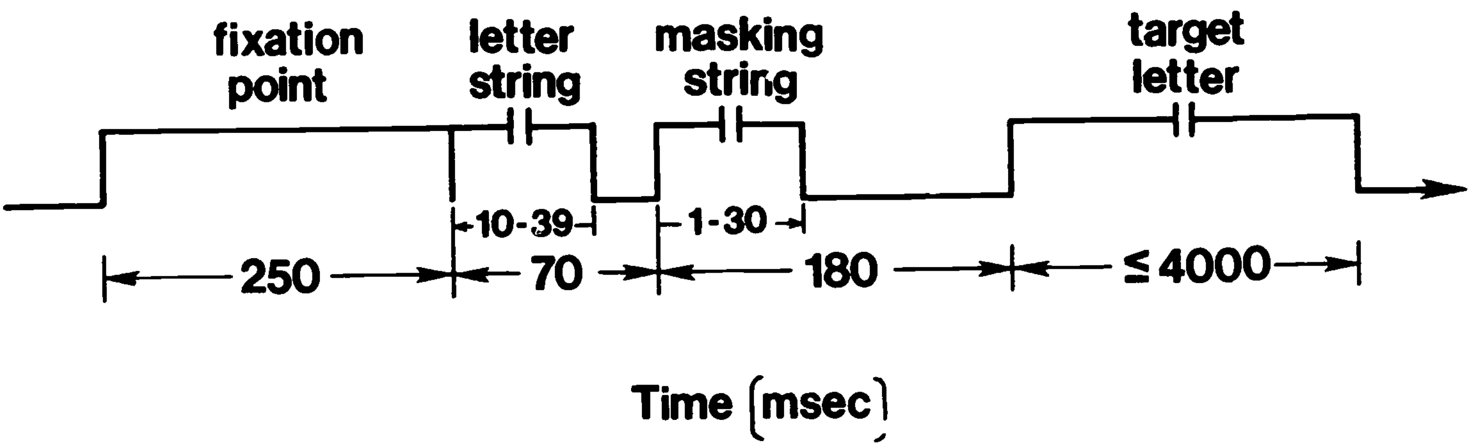



Figure 3. A schematic representation of the perceptual recognition task used in Experiments 1-7.

180 msec minus the duration of the mask. Therefore, the interval between the onset of the test letter string and the target letter was always 250 msec. The target letter remained on the screen until all subjects responded or for a maximum of four seconds. Finally, the interval between trials was 500 msec.

Subjects were instructed to indicate whether the target letter was present in the test string and to be as accurate as possible. The experiment consisted of a session of 100 practice trials with a practice list that was comparable to the experimental list and two sessions of 400 experimental trials each. Within each session, each item was tested once as a target string and once as a catch string. On target trials, the target letter was selected randomly with replacement from the six letters in the test string. For catch trials, a target was selected randomly from the set of 26 letters weighted by their probability of occurrence in the stimulus set. If the selected letter was present in the test string, additional drawings with replacement were made until an appropriate target letter was selected. Some letters did not occur in the test strings and therefore were never tested. A short rest break intervened between the two experimental sessions. The total time for the three sessions and the rest break was about 75 minutes. Both experiments were conducted in exactly the same manner except that different subjects and different items were used in each.

Results

Two analyses of variance were performed on the percentage accuracy scores In the first analysis, word frequency,type of test letter string, target or catch trial, and subjects were factors. In the second analysis, the word data were eliminated and regularity and bigram frequency were factors in the design. Figure 4 shows the average percentage correct on target and catch trials as a function of letter-string type in Experiment 1. There were large differences among the various types of letter strings, $F$ (4, 32) = 130.7, $p < .001$. Regular items resulted in a 9.3% accuracy advantage over irregular items $F$ (1, 8) = 74.7, $p < .001$, while items of high summed-positional bigram frequency had 2.5% advantage over items of low summed-positional bigram frequency, $F$ (1, 8) = 11.4, $p < .01$. The advantage of high bigram frequency was limited to regular items, $F$ (1, 8) = 10.0, $p < .05$. The difference in accuracy between words and the regular-high anagrams was 12.0%, $F$ (1, 32) = 23.3 $p < .001$. There was no difference in accuracy between target (72.4%) and catch (77.2%) trials, $F < 1$, and this variable did not interact with letter-string type, $F < 1$.

Figure 5 gives the average percentage correct for the high and low word frequency words and their anagrams as a function of letter string type. There was an overall 2.7% advantage for the low-frequency words and their anagrams, $F$ (1, 8) = 9.86, $p < .015$, and word frequency also interacted

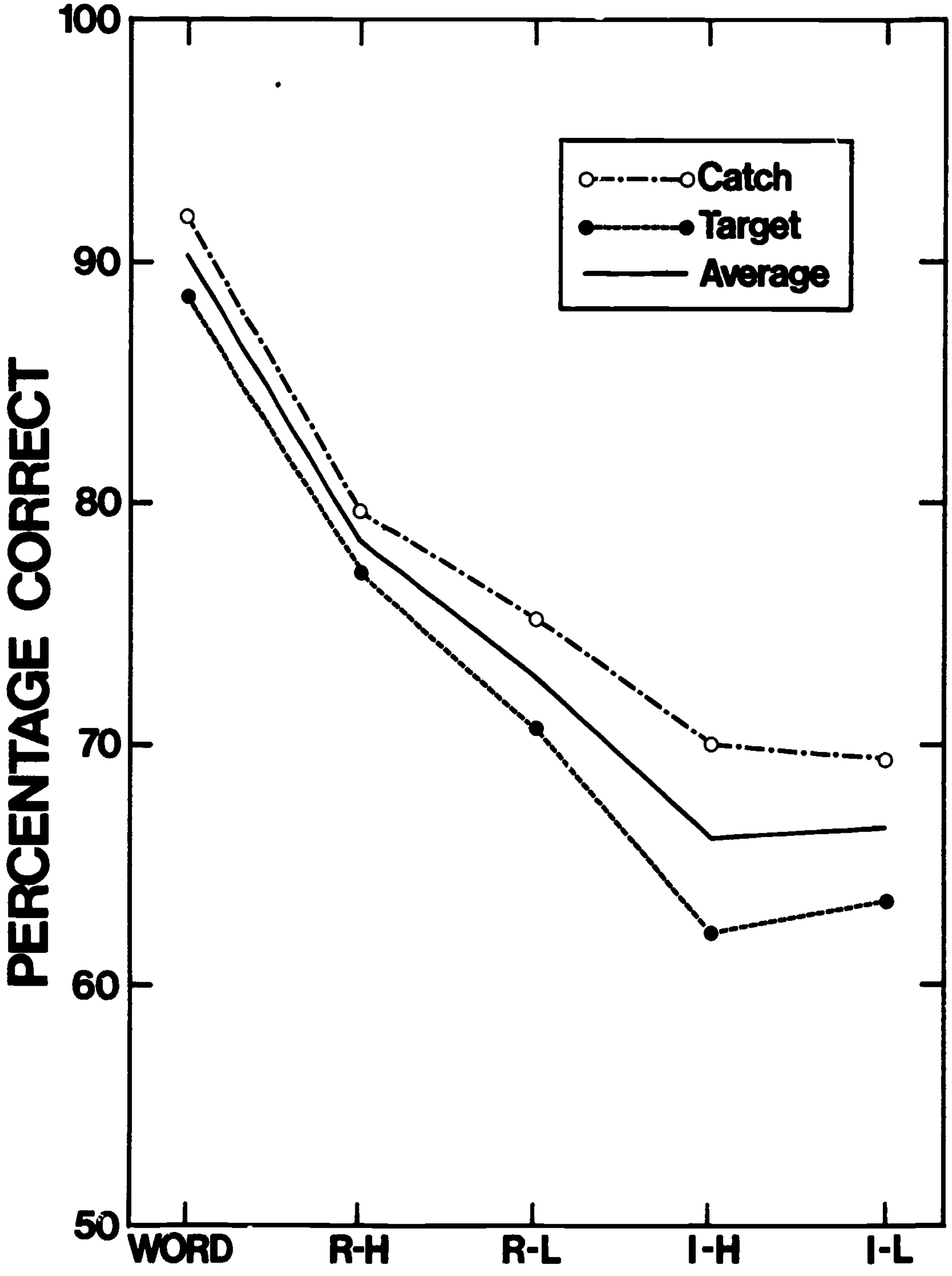



Figure 4. Percentage correct as a function of display type for target and catch trials in Experiment 1.

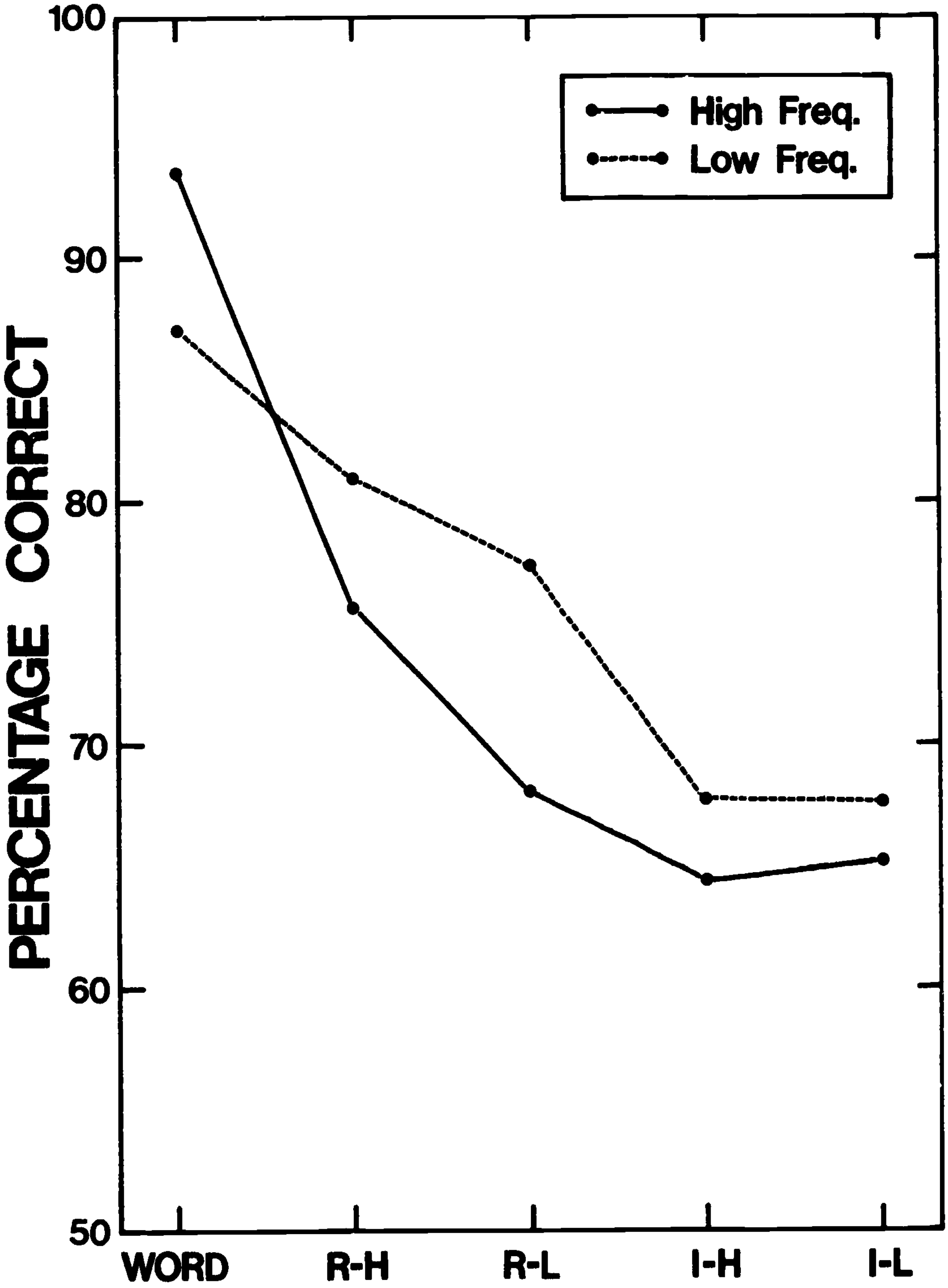



Figure 5. Percentage correct as a function of display type for items corresponding to high and low word frequency in Experiment 1.

with letter-string type, $F(4, 32) = 6.18$, $p < .001$. The overall effect of letter-string type was 28.3% for the high-frequency words and their anagrams and 19.5% for the low-frequency words and their anagrams. This difference reflected the fact that high-frequency words were more accurate than low-frequency words, but that the reverse was the case for the four types of anagrams. Word frequency did not interact with target vs. catch trials nor was there a three-way interaction with these variables and letter-string type ($F$s $< 1$).

Figure 6 gives performance for target and catch trials as a function of letter-string type in the second experiment using new items and new subjects. There were large differences among letter-string types, $F(4, 40) = 92.76$, $p < .001$. Regular items resulted in 8.7% greater accuracy than irregular items, $F(1, 10) = 49.1$, $p < .001$. Items of high summed-positional bigram frequency resulted in 3.3% greater accuracy than items of low summed-positional bigram frequency, $F(1, 10) = 12.2$, $p < .05$, but the advantage occurred only for regular items, $F(1, 10) = 8.2$, $p < .025$. The difference between words and regular-high anagrams was 13.1%, $F(1, 40) = 18.0$, $p < .001$). There was no difference in accuracy between target (74.1%) and catch (78.4%) trials, $F < 1$, and this variable did not interact with letter string type, $F < 1$.

Figure 7 gives average percentage correct for the high and low word frequency words and their anagrams as a

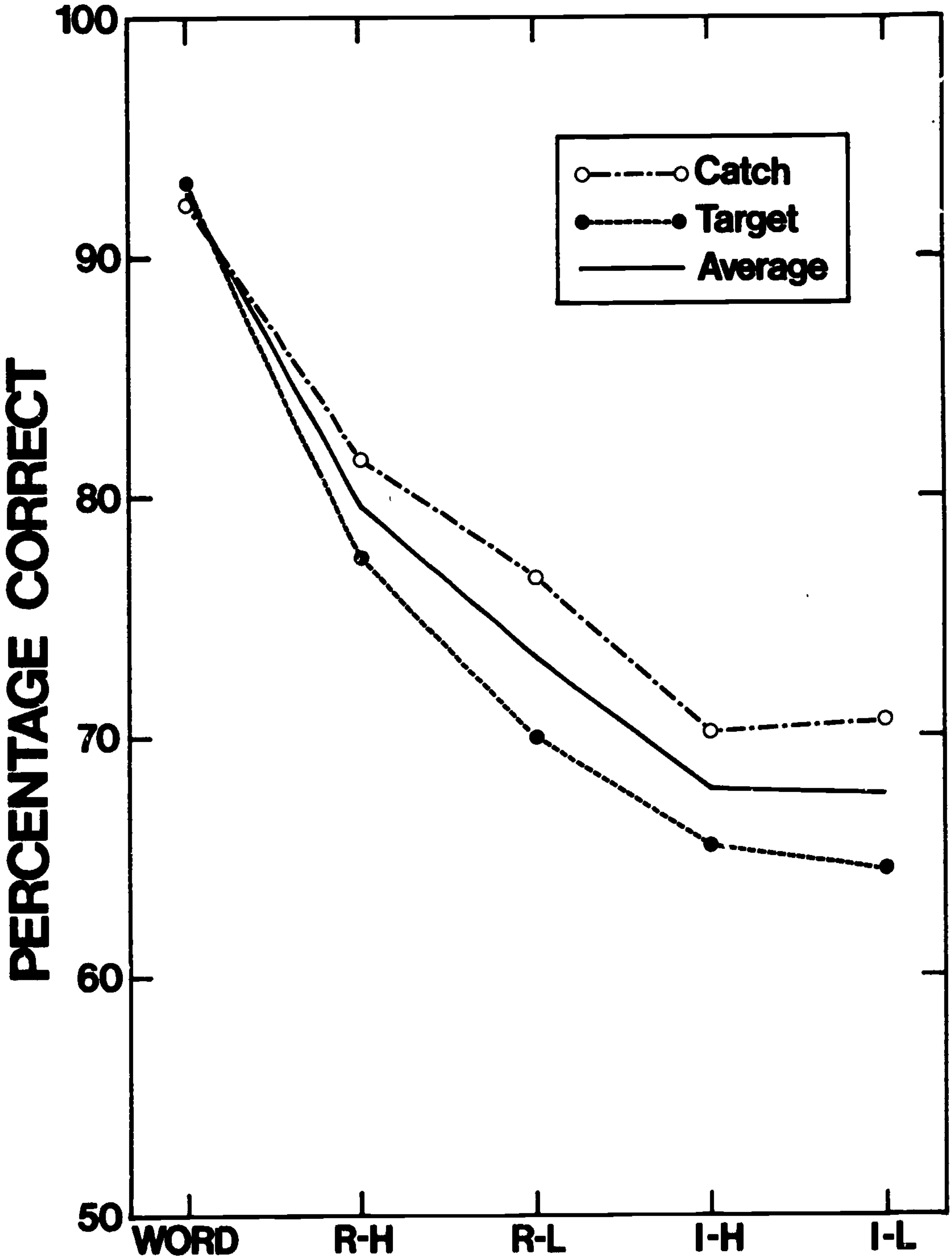



Figure 6. Percentage correct as a function of display type for target and catch trials in Experiment 2.

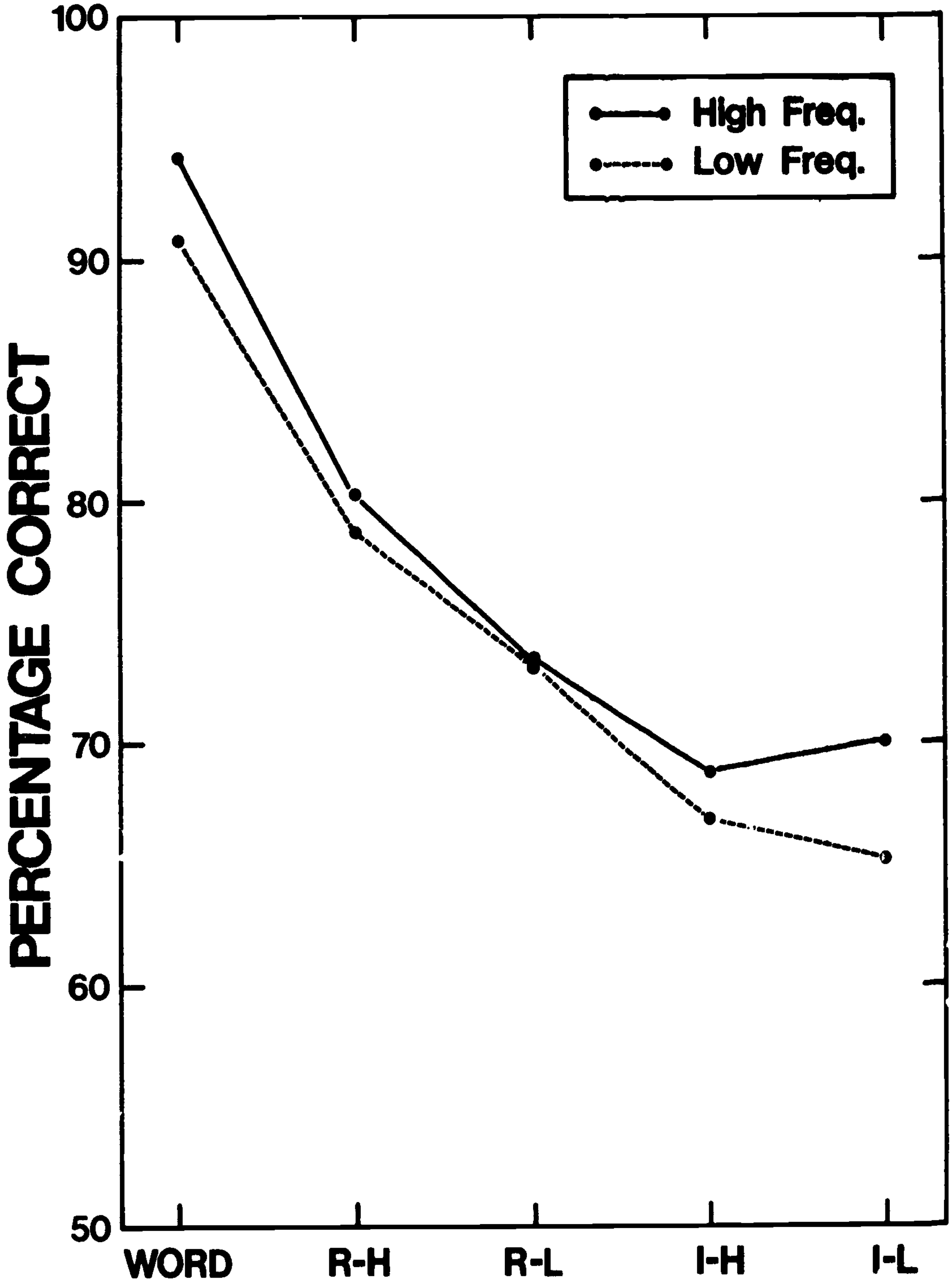



Figure 7. Percentage correct as a function of display type for items corresponding to high and low word frequency in Experiment 2.

function of letter string type. There was a 2.5% advantage for items of the high-frequency words, $F$ (1, 10) = 4.87, $p$ < .052, but word frequency did not enter into any interactions. The overall effect of letter-string type was 24.3% for high-frequency items and 25.8% for low-frequency items. The interaction of word frequency and letter-string type found in the first experiment and shown in Figure 4 was not replicated in the second experiment, $F$ (4, 40) = 1.15, $p$ > .25.

Correlational analysis

The factorial design is limited in terms of providing a quantitative assessment of the importance of frequency and regularity measures of orthographic structure. The present design contrasted just one frequency measure against just one regularity measure. Therefore, post hoc correlational analyses were carried out to provide an analysis of a range of descriptions of orthographic structure. The independent variables used in this analysis included a number of measures based on frequency counts for letters, n-grams, and words, in addition to a few quantitative measures based on orthographic rules. The dependent measure in all cases was average accuracy for each six-letter test item. The accuracy scores were obtained by averaging across subjects and across target and catch trials. Each of the two experiments used 40 words, 20 each of high and low word frequency, and four corresponding anagrams for a total of

200 stimulus items per experiment. Each subject had been presented with each item twice as a target trial and twice as a catch trial. Accordingly, the accuracy score for each item in the first experiment was based on 36 observations (4 replications x 9 subjects) while the accuracy score for the second experiment was based on 44 observations (4 replications x 11 subjects).

Frequency Measures

The source of the frequency measures is based on a word corpus compiled by Kucera and Francis (1967). This corpus consisted of 500 samples of approximately 2,000 words each selected from 15 categories. A description of the corpus, its selection, and its processing are presented by Kucera and Francis (1967, pp. xvii-xxv). Massaro et al. (1980) used these words to derive the frequencies of occurrence of single letters, bigrams, and trigrams. A magnetic tape of the word count produced from the corpus (i.e., the "Rank List" in Kucera & Francis) was obtained. The words were sorted into 10 lists consisting of 1- to 10-letter words, respectively. Words longer than 10 characters were deleted as were items containing numbers, punctuation, or special codings for capitalizations, foreign alphabets, and unusual graphic features or symbols. This resulted in 10 lists of words, one for each letter length. These word lists formed the basis for counts of single letters, bigrams, and trigrams.

Tables were prepared by counting the occurrence of each *n*-gram at the position it occurred in words of a given length. The counts were token counts based upon the total number of occurrences of the words containing the *n*-gram. A position-insensitive count (but still word length dependent) was also obtained for each *n*-gram by summing across the position-dependent counts. Because Kucera and Francis maintained a faithful count of the actual graphic patterns found in the corpus, their list contains rare words, typographic errors, foreign person and place names, and other ideosyncratic items. To limit the impact of such items on these tabulations, cut-off limits were established for both word frequency and number of samples. The cut-offs were a minimum of one occurrence in each of at least three samples. Thus, unusual words and usages, regardless of their frequency, were ignored unless they occurred in three or more separate samples. Although this limit was arbitrary, inspection of the word list in the low frequency range indicated that these were reasonable cut-offs. The single-letter tables and bigram tables for word lengths 3 through 7 are presented in Massaro et al. (1980).

Type counts are based on the number of word types that contain a given *n*-gram and these counts may also be relevant descriptors of frequency-based measures of orthographic structure (Solso & King, 1976). However, Massaro et al. (1980) found that the correlations between comparable type measures and token measures were very high. Measures based on single letters, bigrams, and trigrams, both position sensitive and position insensitive, correlated between .84 and .99. With such high correlations no meaningful discrimination between type and token measures can be made unless test items are selected with this contrast in mind. For this reason we will discuss only measures based on the token counts derived by Massaro et al. (1980).

The present analysis will be restricted to position-sensitive counts. Massaro et al. (1980) found that position-sensitive counts give consistently better descriptions of performance than do position-insensitive counts. For single-letter frequency, for example, the correlation with average accuracy was only .2 for position-insensitive counts but .62 for position-sensitive counts. The advantage of position sensitivity was attenuated, however, as the length of the n-gram increased.

While the effects of frequency seem to be psychologically real, it is not necessary that the mental representations of frequency directly reflect the frequency of objective counts. One alternative scale that has been successful in other research is a logarithmic (base 10) scale. Not only are there some data to suggest the possibility of a logarithmic representation (Massaro et al. 1980; Solomon & Postman, 1952; Travers & Olivier, 1978; Taylor, Note 2), but also a logarithmic representation is consistent with recent studies of number representation (Shepard & Podgorny, 1978) and with many other psychological scales. Therefore, we computed all of our frequency measures based upon both regular linear frequencies and log frequencies. Since counts were sometimes zero, the log of zero was defined as zero. Therefore, the two sets of measures being correlated were sums of position-dependent single letters, bigrams, and trigrams derived from either linear-frequency or log-frequency tables.

Regularity Measures

To provide a quantitative measure of the regularity of each of the 400 stimulus items, a simple count of the number of orthographic irregularities for each item was computed based on the rules developed by Massaro et al. (1980). The rules are given in Table 2. This measure of regularity provided a reasonable description of performance in the Massaro et al. (1980) studies. We will refer to this measure as Regularity(1). One critical feature of the rules for Regularity(1) is that letter strings are treated as monosyllabic and many legal and occurring medial consonant clusters are treated as irregular. For example, the word person would be considered to have an irregularity since according to rule 2, the medial consonant cluster rs would not be legal in initial position. However, the consonant cluster rs is regular in medial position when considered as part of a two syllable word. Therefore, a second quantitative measure of regularity was derived that removed the constraint that the letter string must be considered as

Table 2

The rules for an Irregularity Count (after Massaro et al. 1980).

1. Segment string into vowel and consonant substrings. Treat final -le as if it were -el. Treat h between vowels as a (legal) consonant.
2. For each consonant string, determine minimal number of vowels which must be inserted to make the string pronounceable. Initial consonant clusters must be legal in initial position. Final consonant clusters must be legal in final position, including those followed by final e. Medial consonant clusters must be legal in initial position.
3. Rate each resulting consonant substring for position-sensitive scribal regularity (count one for each irregular substring).
4. For each vowel substring, determine minimal number of consonants which must be inserted to create scribally regular sequences. Mark as irregular illegal initial and final vowel substrings.
5. Count number of inserted vowels and consonants plus number of scribally irregular consonant and vowel substrings. This yields an irregularity index.
6. The vowel string ao, ae, oe, and ue (among more obvious cases) would be illegal vowel strings. u would be illegal as a vowel in initial position and i, u, a, oa, and o would be illegal in final position. ue is legal as is y as a single, non-initial vowel.
7. h is not allowed in final position unless preceded by c, g, or s.
8. y and w between vowels are to be counted as consonants.

a monosyllabic string. This measure is referred to as Regularity(2).

The rules for Regularity(2) were identical to those for the first measure except that the application of the rules and the counting of the violations were carried out in order to minimize the number of violations for any given letter string. When possible, a syllable boundary was assumed in order to avoid a given violation. As an example, the medial consonant cluster md in the string limder would be an illegal consonant cluster in the same syllable because of the phonological rule governing the place of articulation of nasals followed by stops in a single syllable. The nasal and the following stop must share place of articulation; therefore mb and nd are possible but not md or nb. A syllable boundary between m and d in limder is possible, however, resulting in a perfectly legal two-syllable string with no violations. Similarly, in the string nurdgi the medial consonant cluster rdg is legal with a syllable boundary between d and g. The only violation is i in final position.

## Frequency vs. Regularity

The correlations of several measures with average accuracy are presented in Table 3. The correlation needed for statistical significance at $p = .01$ with 198 degrees of freedom is .18. Of central interest is the relative ability of bigram frequency and regularity measures of orthographic

Table 3
Correlations of Several Predictor Variables With Overall Accuracy Performance in Experiments 1 and 2

| | Experiment 1 | Experiment 2 |
|---|---|---|
| Dummy Regularity | .49 | .51 |
| Dummy Frequency | .26 | .37 |
| Single Letter | | |
| linear | .32 | .28 |
| log | .36 | .49 |
| Bigram | | |
| linear | .35 | .29 |
| log | .54 | .63 |
| Trigram | | |
| linear | .47 | .46 |
| log | .60 | .64 |
| Word Frequency | | |
| linear | .45 | .51 |
| log | .55 | .59 |
| dummy | .60 | .68 |
| Regularity Count(1) | .52 | .51 |
| Regularity Count(2) | .54 | .55 |

structure to predict performance. Two dummy variables were created to contrast these two measures while equating for the range and levels of each measure. The dummy regularity variable assigned a 1 to words and regular nonwords, and a 0 to irregular nonwords. The dummy frequency variable assigned a 1 to words and high bigram frequency nonwords, and a 0 to low bigram frequency nonwords. In both experiments the regularity variables correlated much higher (.49, .51) with performance than did the frequency variable (.26, .37).

It is not possible to choose between regularity and frequency measures of orthographic structure. Although the regularity counts do better than linear frequency counts and log single letter counts, log bigram and log trigram counts do better than regularity. Both measures account for a significant portion of the variance in performance. Regularity and frequency measures are positively correlated with each other. As an example, log trigram frequency and Regularity(2) correlate .47 and .46 for the items in Experiments 1 and 2, respectively. A multiple regression was carried out treating the summed frequency counts and the irregularity counts as independent variables. The best combination of predictors was log trigram frequency and Regularity(2), which accounted for 45% of the variance in Experiment 1 and 49% in Experiment 2.

Word Frequency

Linear word frequency correlated .45 and .51 while log word frequency correlated .55 and .59 with performance in the two experiments. The correlation with performance on just the 40 word items were .46 and .51 for linear and log frequencies in the first experiment and, .34 and .35 in the second experiment. Log word frequency was highly correlated with both log bigram frequency (.50, .52) and log trigram frequency (.77, .74). A dummy word frequency variable which assigned a 1 to words and a 0 to nonwords was more highly correlated (.60, .68) with performance than was log word frequency. Although it is possible that lexical status makes an independent contribution to performance, the high correlations between word frequency and sublexical orthographic structure measures preclude resolution of this issue.

## Serial Positon

The correlations between the three log frequency measures at each serial position and overall performance are shown in Figures 8 and 9. In general, the frequency of *n*-grams at the beginning and end of the items predicts performance better than *n*-grams in the middle. To evaluate whether this effect is due to the informational constraints in the stimuli themselves, we derived a measure of redundancy or predictability for each serial position. The variance of letter occurrences at each serial position was computed based on the table of frequencies given by Massaro

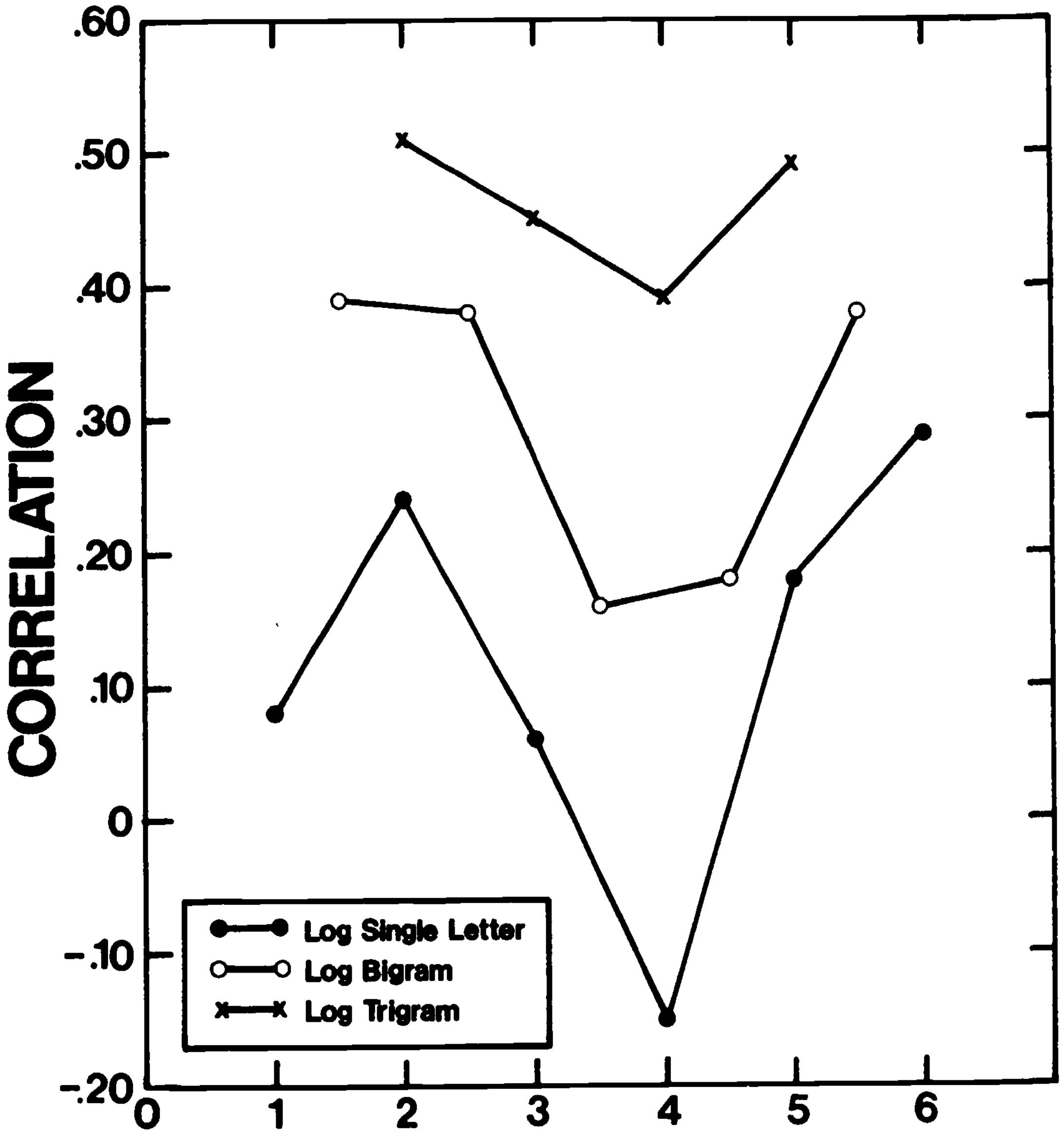



Figure 8. Correlations of accuracy with log single-letter, log bigram, and log trigram frequencies as a function of their respective serial positions in the six-letter strings in Experiment 1.

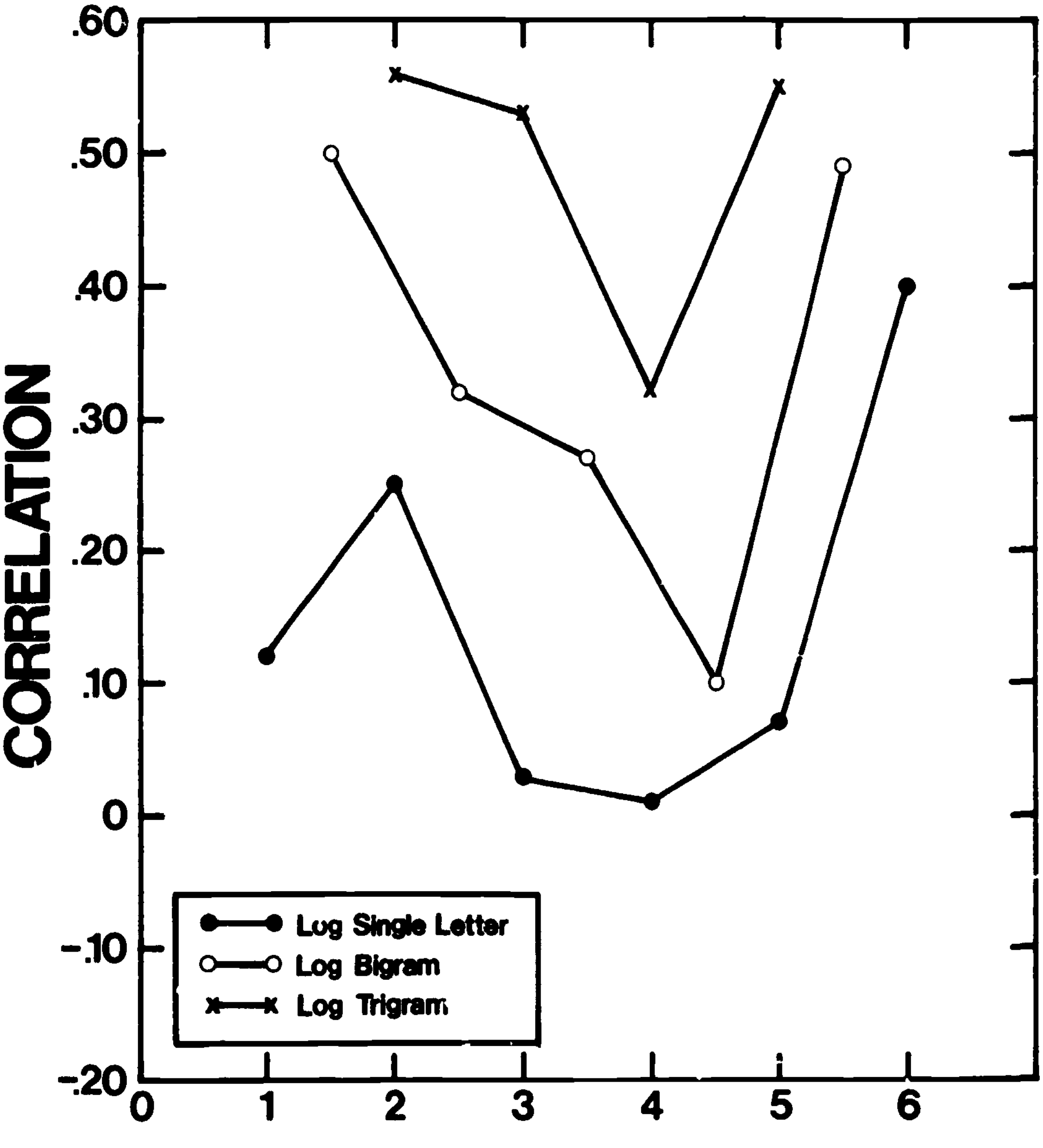



Figure 9. Correlations of accuracy with log single-letter, log bigram, and log trigram frequencies as a function of their respective serial positions in the six-letter strings in Experiment 2.

et al. (1980). High variance occurs to the extent that some letters occur more often and, therefore, are more predictable than others. These variance measures for the log single-letter, log bigram and log trigram counts are shown in Figure 10. For single letters there is less redundancy at the middle positions relative to the end positions. There is very little change in redundancy across serial positions for the bigram and trigram measures. The redundancy and performance measures are nicely correlated for single letters, but uncorrelated for bigrams and trigrams.

A second measure of redundancy was calculated by taking an average uncertainty measure H, based on Shannon's (1948, 1951) equation,

$$H = \sum_{1}^{N} P \log(1/P)$$

where P is the probability of occurrence of a letter or letter cluster at a given position and, N is the total number of letters or letter clusters that occur at that position. These uncertainty measures are presented in Figure 11. Uncertainty measures the degree to which letters or letter clusters are unpredictable; we might expect better correlations with performance at those serial positions with small values of uncertainty.

As can be seen Figure 11, the uncertainty measures do a good job of predicting the performance measures for single letters. The only discrepancy is in the fifth letter position where subjects failed to exploit the redundancy at

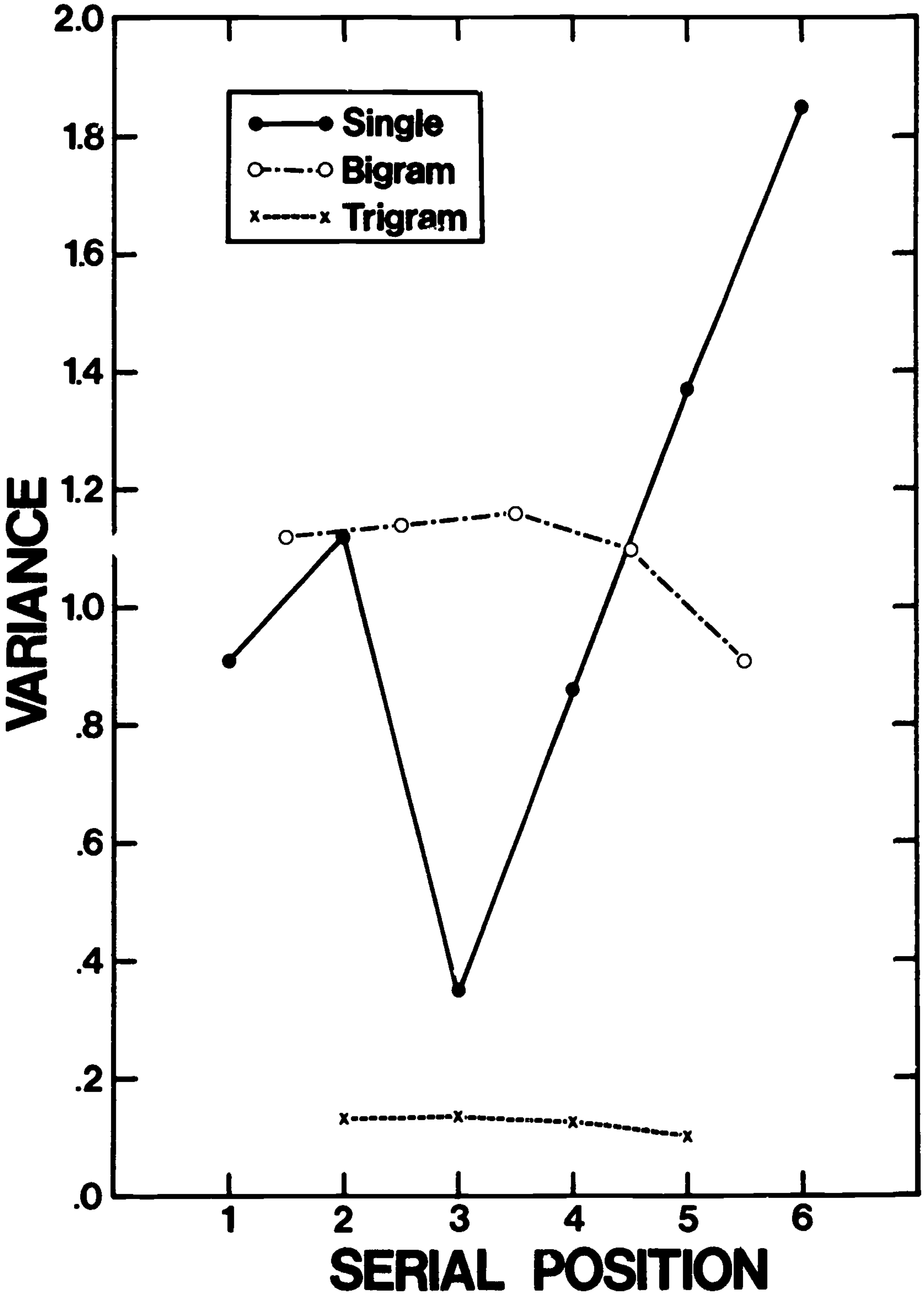



Figure 10. Variance of linear and log single-letter, bigram, and trigram occurrences at the respective serial positions in the six-letter strings.

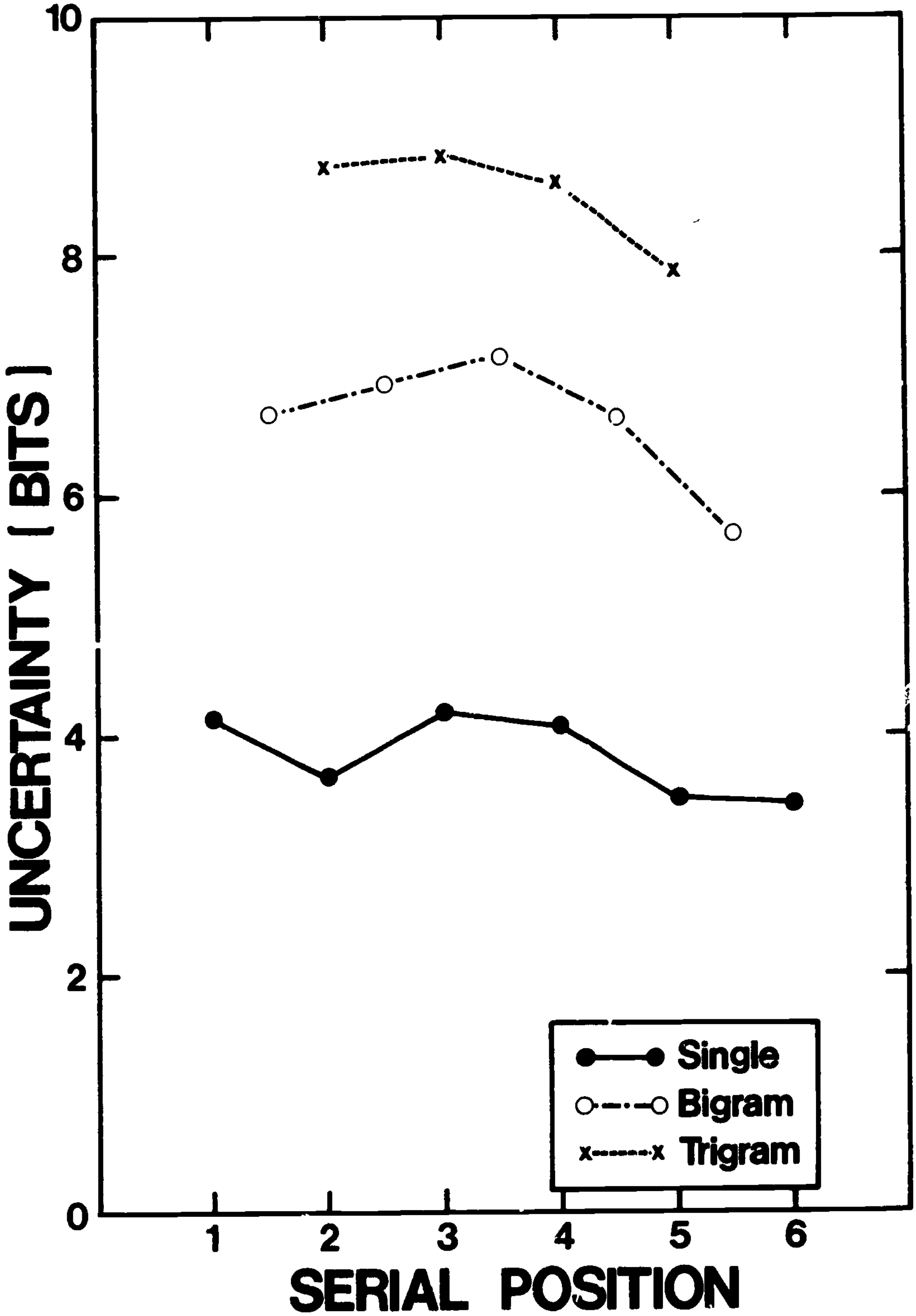



Figure 11. Shannon's uncertaintly measure H, for single-letter, bigram and trigram occurrences at the respective serial positions for six-letter words.

this position. There is also a reasonable correspondence for the bigram counts. However, the initial bigram predicts performance better than the final bigram even though the latter has less uncertainty. There is no correspondence between the uncertainty measures and the performance correlations for the trigram counts.

Multiple Regressions

In a series of multiple regression analyses, the individual log counts at each serial position were treated as independent variables. Of concern was which serial positions made statistically significant contributions in accounting for the variance in the data. The orders in which the serial positions were entered in the equations were 3, 2, 5, 6, 4, and 1 for single-letters, 1, 3, 5, 4, and 2 for bigrams, and 1, 3, 4, and 2 for trigrams. The log single-letter counts at the sixth, second, and positions accounted for 18% of the variance in Experiment 1. An analogous analysis in Experiment 2 accounted for 21% of the variance with positions 6, 2, and 1. For log bigrams, the first, fifth, and second positions accounted for 32% of the variance in Experiment 1. In the second experiment, the log bigram counts at the first, fifth, and third positions accounted for 45% of the variance. For log trigrams, the first, fourth, and second positions accounted for 38% and 47% of the variance in Experiments 1 and 2 respectively.

Regressions were also conducted for summed log single-letter, bigram, and trigram frequencies and regularity. Summed log bigram frequency and regularity were always entered into the equation first. For the first experiment, bigram frequency and regularity accounted for 35% of the variance. With these two variables in the regression equation, the partial correlations for the log single-letter and trigram frequencies were -.05 and .39, respectively. For the second experiment, bigram frequency and regularity accounted for 42% of the variances and the partial correlations for log single-letter and trigram frequencies were .08 and .36, respectively.

## Experiment 3

The creation of the stimulus set for Experiment 3 was identical to that of the previous experiments except that log bigram rather than linear bigram counts were used and the strings were controlled more exactly for regularity. Figure 12 gives examples of the five classes of items and the average log bigram frequency for each class. The complete list of letter strings is presented in Appendix 3.

In the studies of Massaro et al. (1980) and Experiments 1 and 2 log-frequency measures gave consistently better descriptions of performance than did linear-frequency measures. Furthermore, Massaro et al. (1980) found that the log counts were superior to a range of power-function transformations of the linear counts. This result provides

| Words | |
|---|---|
| High word frequency | period, should (15.033) |
| Low word frequency | coined, magnet (13.420) |

| Orthographic Regularity | Summed Positional Log Bigram Frequency: High | Summed Positional Log Bigram Frequency: Low |
|---|---|---|
| Regular | rodipe, shulod (11.688) | dripoe, lohuds (8.523) |
| | diceon, tamgen (11.143) | nidcoe, nemtag (7.842) |
| Irregular | prdioe, dhouls (11.625) | dpireo, louhds (8.509) |
| | cnoied, ntagem (11.083) | endcoi, nagtme (7.883) |

Figure 12. Examples of the test words and their corresponding anagrams from Experiments 3 and 4. Within each of the five squares, the top two items correspond to high word frequency and the bottom two items correspond to low word frequency. The number in each of the ten cells represents the summed positional log bigram frequency.

additional evidence that if frequency of occurrence is important, log frequency appears to be the best descriptor of this variable.

A count of the number of irregularities in each letter string was determined using the rules for Regularity(3) presented in Table 4. The rules for Regularity(3) were the same as for Regularity(2) except that vowels as initial letters violated one of the rules and therefore were counted as irregularities. Given this formula, it was now possible to equate the number of irregularities for the anagrams that differed only in log bigram frequency. In our previous studies, the number of irregularities tended to correlate negatively with frequency and some of the effect of frequency could have been due to differences in regularity. This possibility was eliminated in the present study by equating the high- and low-frequency anagrams of a given test word for the number of irregularities. Consider the test word period shown in Figure 12. The regular high and regular low anagrams (rodipe and dripoe) do not have any irregularities. The irregular high and irregular low anagrams (prdioe and dpireo) have 2 irregularities each. This design might provide a more definitive contrast between frequency and regularity.

## Method

Subjects. Nine University of Wisconsin summer school student volunteers were used as subjects and paid $9.00 for

Table 4
Rules for Regularity(3) for the Selection of the Items Used in Experiments 3-6.

1. For each string, rate for position-sensitive scribal regularity and pronounceability (count one for each violation). Treat final -le as if it were -el. Treat h between vowels as a (legal) consonant.

2. For each string, rate for position-sensitive scribal regularity and pronounceability (count one for each violation). Initial consonant clusters must be legal in initial position. Final consonant clusters must be legal in final position including those followed by final e.

3. For each string, rate for position-sensitive scribal regularity and pronounceability (count one for each violation). The vowel strings ao, ae, oe, and ye (among more obvious cases) would be illegal vowel strings. All vowels are illegal in initial position and y would be illegal as a vowel in initial position. The vowels i, u, a, oa, and o would be illegal in final position. ue is legal as is y as a single non-initial vowel. n is not allowed in final position unless preceded by c, g, or s. y and w between vowels are to be counted as consonants.

their participation. All were native English speakers, had normal or corrected vision, and had not participated in any of the other experiments.

Stimuli and apparatus. Words were selected in the same manner as in previous two experiments. The high-frequency words had a Kucera and Francis (1967) frequency of at least 50, and the low-frequency words had a frequency of 3. Due to a selection error, one low-frequency word had a frequency of 4. For each of the 80 words, four anagrams were selected so that they formed a factorial arrangement of high and low summed-positional log bigram frequency and of being orthographically regular or irregular. For each set of four anagrams, the number of irregularities were matched exactly for the regular conditions and then again for irregular conditions. Finally, an additional sample of words, 13 high and 13 low in word frequency, and their anagrams were selected as practice items.

The 80 experimental words and their anagrams were divided into two lists. List 1 contained one-half of the high word frequency items and one-half of the low word frequency items. List 2 contained the remaining items.

Stimuli were presented in the same manner and on the same equipment as in the previous experiments with only one exception. The range of durations for the test letter strings was 5-39 msec. Because of the algorithm used, decreasing the lower limit for the duration of the test string increased the maximum duration of the mask to 35 msec.

Procedure. The experiment was conducted in a manner similar to that of the previous experiments. The presentation of the test string, masks, and target letters was indentical to that of Experiments 1 and 2. Subjects were tested on two consecutive days. At the beginning of each day, subjects began with a practice session of all 260 trials. Two experimental sessions of 400 trials each followed the practice. Five of the subjects received all 200 items of List 1 on Day 1 in the first session as both target and catch trials. These subjects then received the List 2 items in the second sesion. On Day 2, List 2 was presented in the first session and List 1 in the second session. For the remaining four subjects, the order of the lists was reversed.

## Results

Figure 13 shows the average percentage correct on target and catch trials as a function of letter-string type. There were significant differences, $F$ (4, 32) = 127.1, $p$ < .001, among the five types of letter strings. Words had a 16% advantage over the regular-high anagrams, $F$ (1, 32) = 55.1, $p$ < .001. There was 4.0% advantage of regular strings over irregular strings, $F$ (1, 8) 32.5, $p$ < .001, and a 1.4% advantage of high log bigram frequency strings over low log

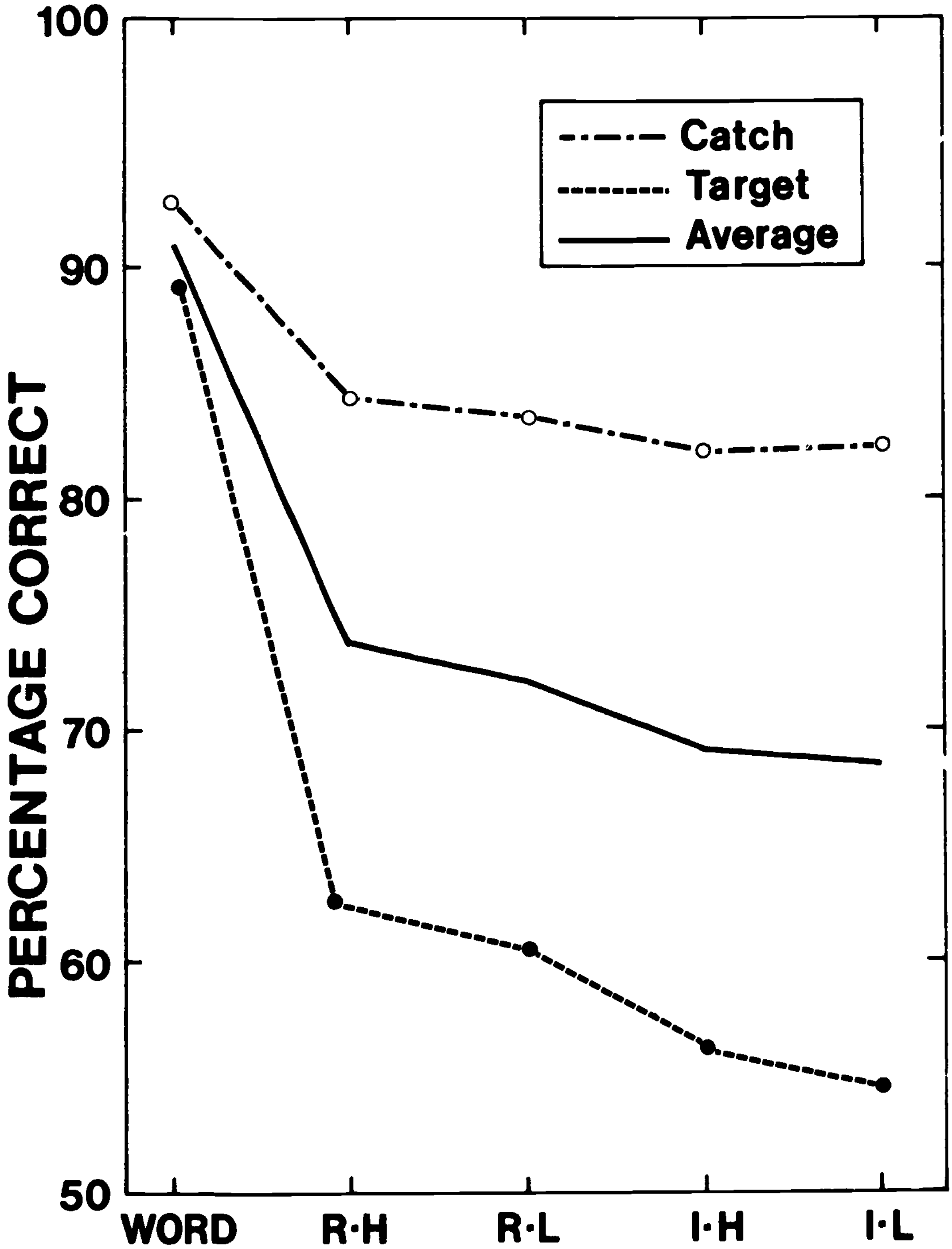



Figure 13. Percentage correct as a function of display type for target and catch trials in Experiment 3.

bigram frequency strings, $F$ (1, 8) = 2.6, $p > .2$.

One disquieting aspect of the results is the extreme asymmetry in performance target and catch trials and the interaction of this variable with display type, $F$ (1, 8) = 12.8, $p < .007$, and $F$ (4, 32) = 9.5, $p < .001$. Subjects were extremely conservative in their willingness to indicate that a target letter was present. This result could reflect our failure to instruct the subjects specifically about the relative frequency of target trials as we did in the previous two experiments.

Figure 14 gives average percentage correct for the high and low word frequency words and their anagrams as a function of letter-string type. High frequency words and their anagrams were recognized 3.2% more accurately than low-frequency words and their anagrams, $F$ (1, 8) = 69.03, $p < .001$. The interaction between word frequency and the five types of items was not significant, showing that this difference was not unique to the word items. Therefore, some variable other than word frequency must be responsible for the difference. However, one caveat is to realize that performance may not be on an interval scale, which weakens any interpretation of the lack of interaction. One solution would be to monitor each display type independently and to adjust the stimulus values to give an average of 75% correct for high and low word frequencies. If word frequency still does not interact with display type when average performance

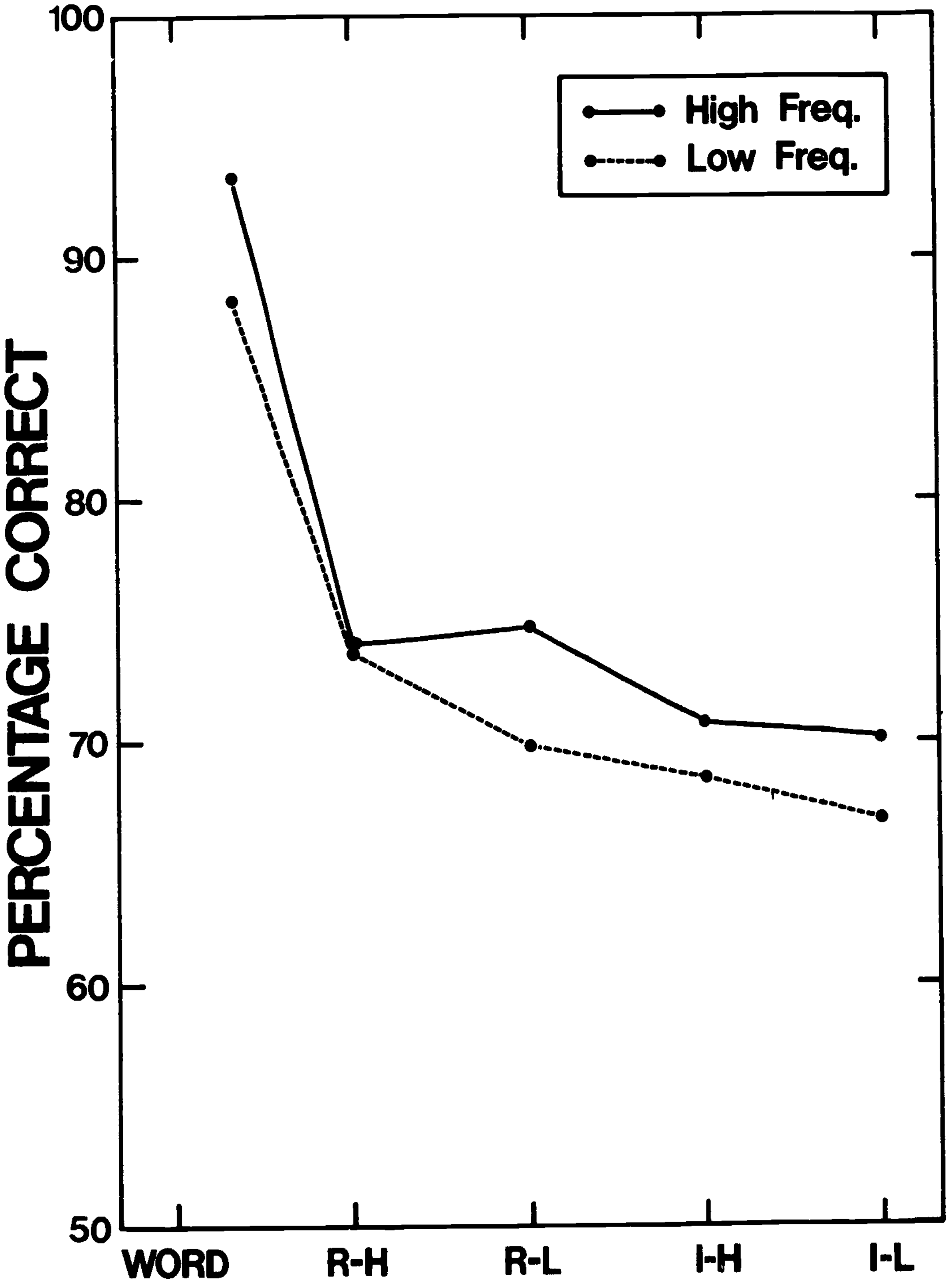



Figure 14. Percentage correct as a function of display type for items corresponding to high and low word frequency in Experiment 3.

is about 75% correct at each display type, then the conclusion reached here would be reinforced.

## Correlational analysis

The correlations of several variables with overall performance presented in Table 5. For all frequency measures, the log measures correlated more highly with performance than did the linear measures. Log trigram frequency predicted performance better than the other sublexical measures. Log word frequency was correlated with accuracy (.60), but also was correlated with log bigram frequency (.61) and log trigram frequency (.80). Among just the high-frequency words the correlation with performance was -.05 and -.13, respectively, for linear and log word frequencies. (Correlations among the low-frequency words would not be meaningful since all the items had the same Kucera and Francis frequency of occurrence). The lack of a significant correlation between performance and word frequency within the class of words replicates previous results (Manelis, 1974) and makes it unlikely that word frequency can account for the effects of orthographic structure. Lexical status alone might be an important variable, however. The dummy variable of word or nonword gave a highly significant correlation of .60 with performance.

## Multiple Regressions

Table 5
Correlations of Several Predictor Variables with Overall Accuracy in Experiment 3 and 4.

| | Ex. 3 | Ex. 4 | Ave. |
|---|---|---|---|
| Single letter | | | |
| linear | .29 | .26 | .31 |
| log | .36 | .28 | .36 |
| Bigram | | | |
| linear | .38 | .33 | .40 |
| log | .53 | .43 | .54 |
| Trigram | | | |
| linear | .44 | .36 | .45 |
| log | .59 | .48 | .60 |
| Word frequency | | | |
| linear | .44 | .37 | .46 |
| log | .60 | .50 | .63 |
| Regularity Count(3) | .40 | .29 | .39 |

Multiple regressions were carried out as in Experiments 1 and 2. The log single-letter counts at the sixth, second, and first letter positions accounted for 12% of variance in Experiment 3. For the log bigram counts, the first, fifth, and second positions accounted for 28% of the variance. Finally, for the log trigram counts, 36% of the variance was accounted for by the first, fourth, and second serial positions.

For the regressions with summed log bigram frequency and Regularity(3) entered into the equation, 35% of the variance was accounted for. The partial correlations for log single-letter and log trigram frequencies were -.07 and .28, respectively.

## Experiment 4

### Method

Eight new University of Wisconsin undergraduates from Introductory Psychology who met the same requirements as in the previous experiments were used as subjects. Experiment 4 was an exact replication of Experiment 3 with one exception. The instructions were modified to inform subjects that a target letter would appear in the test string on 50% of the trials. It was expected that this manipulation would attenuate the asymmetry in the number of positive and negative responses.

### Results

Figure 15 shows the average percentage correct for target and catch trials for the five letter-string types. The significant differences among the letter-string types, $F\ (4, 28) = 102.7$, $p < .001$, completely replicate Experiment 3. There was a 15.0% advantage of words over regular-high anagrams, $F\ (1, 28) = 52.4$, $p < .001$; a 2.4% advantage for regular strings, $F\ (1, 7) = 10.2$, $p < .025$; and only a 0.7% advantage for high-frequency strings, $F\ (1, 7) = .84$.

Though the responding asymmetry was substantially reduced, there nonetheless was still a tendency for subjects to remain conservative in their willingness to indicate that a target letter was present, $F\ (1, 7) = 6.11$, $p < .05$. The range of performance across letter-string types was 23.0% for target trials and 13.3% for catch trials.

Figure 16 presents the percentage correct for the letter-string types as a function of word frequency. There was an overall effect of 20.5% for high word frequency items and 15.8% for low word frequency items, $F\ (4, 28) = 2.19$, $p < .10$.

## Correlation Analysis

The correlations of several measures with overall performance in Experiment 4 are presented in Table 5. As with the previous analyses, log measures predicted performance better than did linear measures. Trigram frequency was the best of the three frequency measures, but only slightly better than bigram frequency. Log word

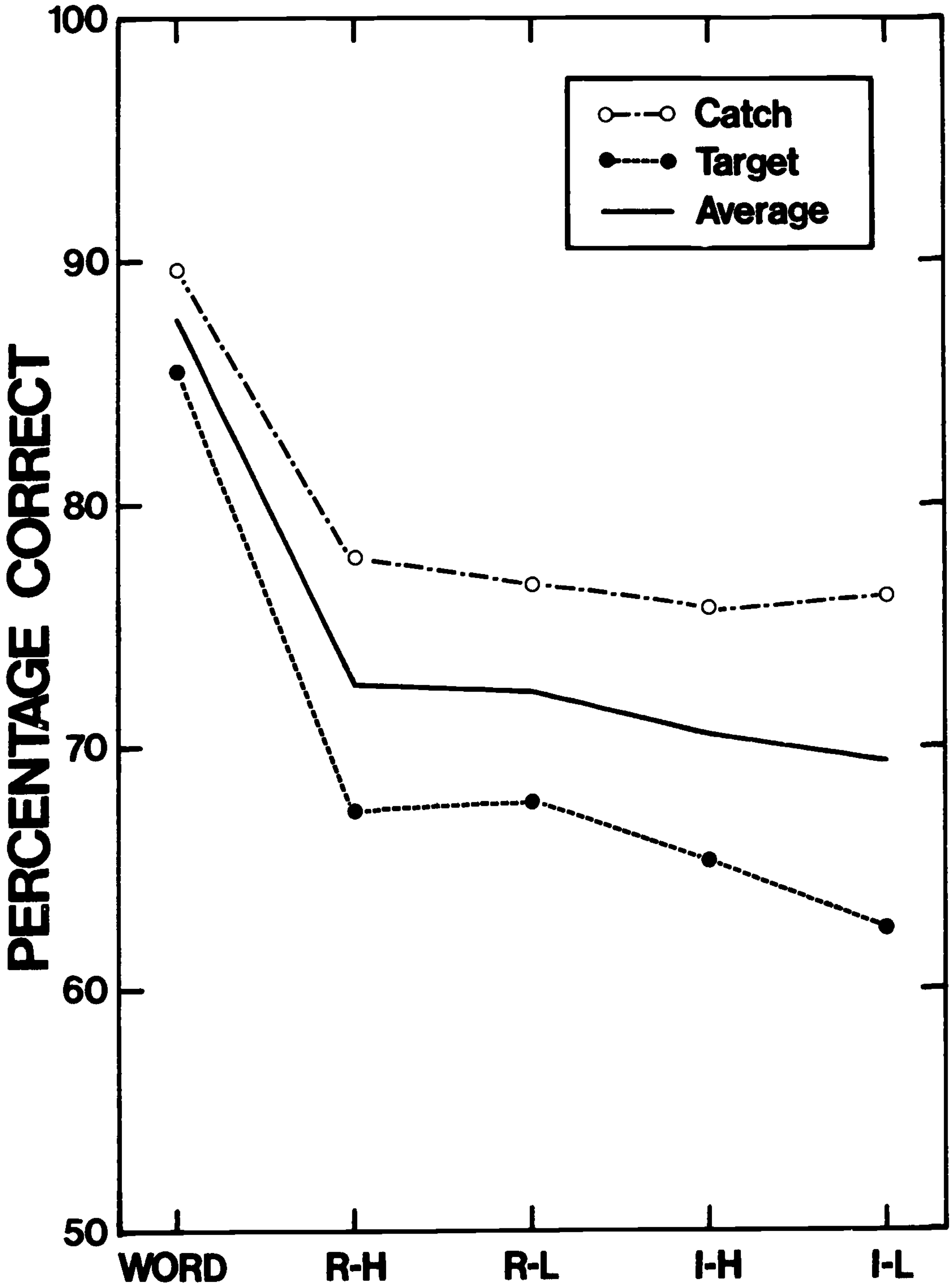



Figure 15. Percentage correct as a function of display type for target and catch trials in Experiment 4.

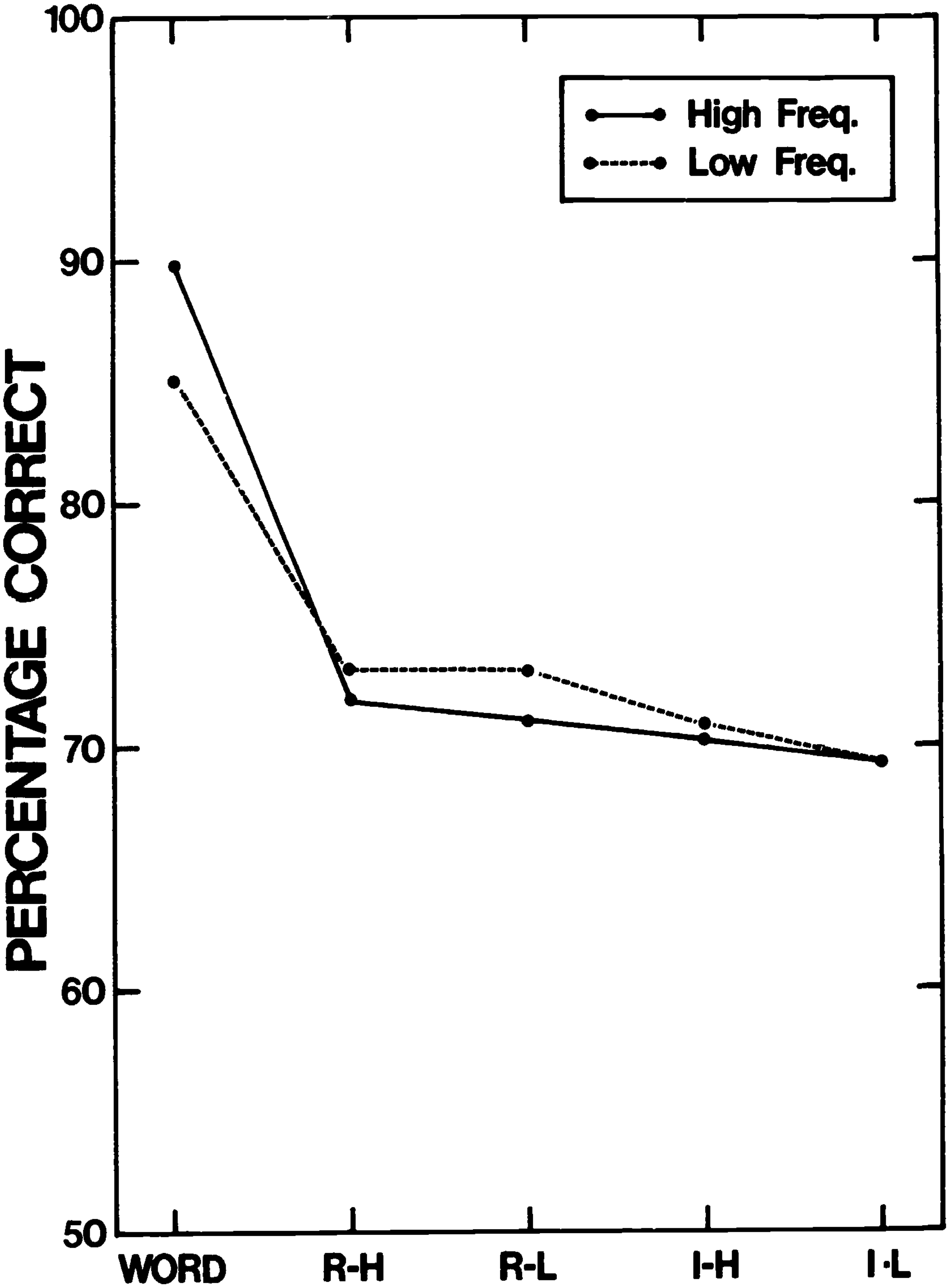



Figure 16. Percentage correct as a function of display type for items corresponding to high and low word frequency in Experiment 4.

frequency was correlated .50 with overall performance. Also presented in Table 5 are the correlations of the same variables with the average performance in Experiment 3 and 4. Since Experiment 4 was a replication of Experiment 3, the performance on each item was averaged across the two experiments. As might be expected from increased reliability, these correlations are significantly larger than for either of the experiments considered separately.

### Multiple Regressions

For log single-letter counts, the sixth, fifth, and second positions accounted for 7% of the variance. For log bigram counts, the first and fifth positions accounted for 16% of the variance. For log trigram counts, the first and fourth positions predicted 25% of the variance.

Summed log bigram frequency and Regularity(3) accounted for 21% of the variance and the partial correlations for log single-letter and log trigram frequencies were -.05 and .22, respectively.

## Experiment 5

### Method

Subjects. Nineteen fourth graders from the Madison Metropolitan School District participated as subjects and were paid $5.00. The children were tested in the middle of the school year, had normal or corrected vision, and were administered the STEP (1979) reading test at the end of third grade. Of the 19, all but five had scored at or above their grade level on the STEP reading test. The STEP scores ranged from 25 to 50 with an average score of 43.

Stimuli and apparatus. The 200 items used were those of List 1 from Experiment 3. Accordingly, one-half of the items were of high word frequency and one-half were of low word frequency. The anagrams represented a factorial arrangement of high or low frequency and regular or irregular. The same practice list as in Experiment 3 also was used.

The stimuli were presented in the same manner and on the same equipment as in Experiment 3 with one exception. The range of durations of the test string presentation was increased to accommodate the less developed processing capabilities of fourth-grade subjects.

Procedure. Subjects were tested in groups of 1-4. Upon arrival for the experiment, the fourth graders spent about 10 minutes in various activities to allow them to adjust to our laboratory. They were then instructed as a group about what the experiment involved. This instruction proceeded in two steps. First, the children listened and watched the experimenter simulate the target search task using index cards. The experimenter showed cards printed with a test string and a target letter and the children responded "Yes" or "No" aloud. After some coaching and about six of these trials, the children performed the task without error. The second step involved explaining the task using the computer equipment. This also was performed as a group and each child attempted about 15 computer-generated trials while the remaining children watched. All adapted to the equipment readily and were able to perform the task. The children were then taken to their individual subject stations in separate rooms and tested on the practice list.

As the children were responding, the computer displayed to the experimenter in an isolated room each child's average accuracy after each trial. This allowed the experimenter to monitor each child's progress, and, if necessary, to adjust the range of durations for the test letter string. The range was adjusted if any subject was not able to achieve 75% accuracy even when the test string appeared for the maximum duration allowed by the range of durations. The nineteen subjects participated in six different groups. The six groups differed in terms of the range of durations that was used and whether a mask appeared. As in Experiments 3 and 4, the minimum string duration for all groups was 5 msec. For three groups, the maximum string duration ranged from 59 to 179 msec. For these groups a mask was used. The minimum mask duration was always 1 msec. The maximum amount of time that the mask remained on the CRT was increased by exactly the same amount that the test-string maximum duration was increased. Accordingly, the maximum mask duration ranged from 55 to 175 msec for the three groups.

The stimulus onset asynchrony (SOA) between the test string and the mask always was equal to the maximum string duration plus 31 msec. As a result, the SOAs ranged from 90 to 210 msec. For all groups the interval between the onset of the test string and the onset of the target letter was increased by exactly the same amount as the increase in the maximum duration of the test letter string (see Figure 1). For example, when the string duration was increased 20 msec, the time between the onset of the string and the onset of the target was lengthened 20 msec. For the remaining three groups of subjects, the maximum string durations ranged from 249 to 499 msec and the mask was eliminated. The target letter followed the test string after an interval equal to the maximum duration of the test string.

Following the 100 practice trials, the subjects were presented with each of the 200 items twice in each of two sessions. Thus, each subject was presented with each item twice on target trials and twice on catch trials. The children were given a five-minute rest period after the practice trials and after every 200 experimential trials. The entire experiment lasted about 90 minutes.

## Results

Despite the widely varying test durations, the six groups of subjects exhibited a similar pattern of results. Therefore, no distinction among the groups was included in the data analysis. One subject was eliminated because his overall accuracy was at chance.

Figure 17 presents the results for the fourth-grade subjects as a function of display type for target and catch trials. Accuracy was higher for better structured letter strings, $F$ (4, 18) = 40.2, $p < .001$. Words were recognized 9.9% better than the regular-high anagrams, $F$ (1, 17) = 15.5, $p < .005$. There was a 3.0% advantage of regular over irregular anagrams, $F$ (1, 17) - 9.2, $p < .01$. Log bigram frequency had only a .2% effect, $F < 1$.

Figure 18 reveals the interaction of display type and word frequency, $F$ (4, 68) = 2.5, $p = .05$. This effect reflected a 4.0% advantage of high frequency words over low frequency words, $F$ (1, 68) = 4.6, $p < .05$.

The slight difference between target (66.9%) and catch (70.8%) trials was not significant, $F < 1$, and this variable did not interact with letter-string type, $F < 1$.

## Correlation Analysis

Table 6 presents the correlations of performance with several predictor variables. Correlations increased from linear to log counts and with increases in the size of the frequency measure. Overall, the pattern of results obtained for the fourth graders is similar to that found for adult subjects.

## Multiple Regressions

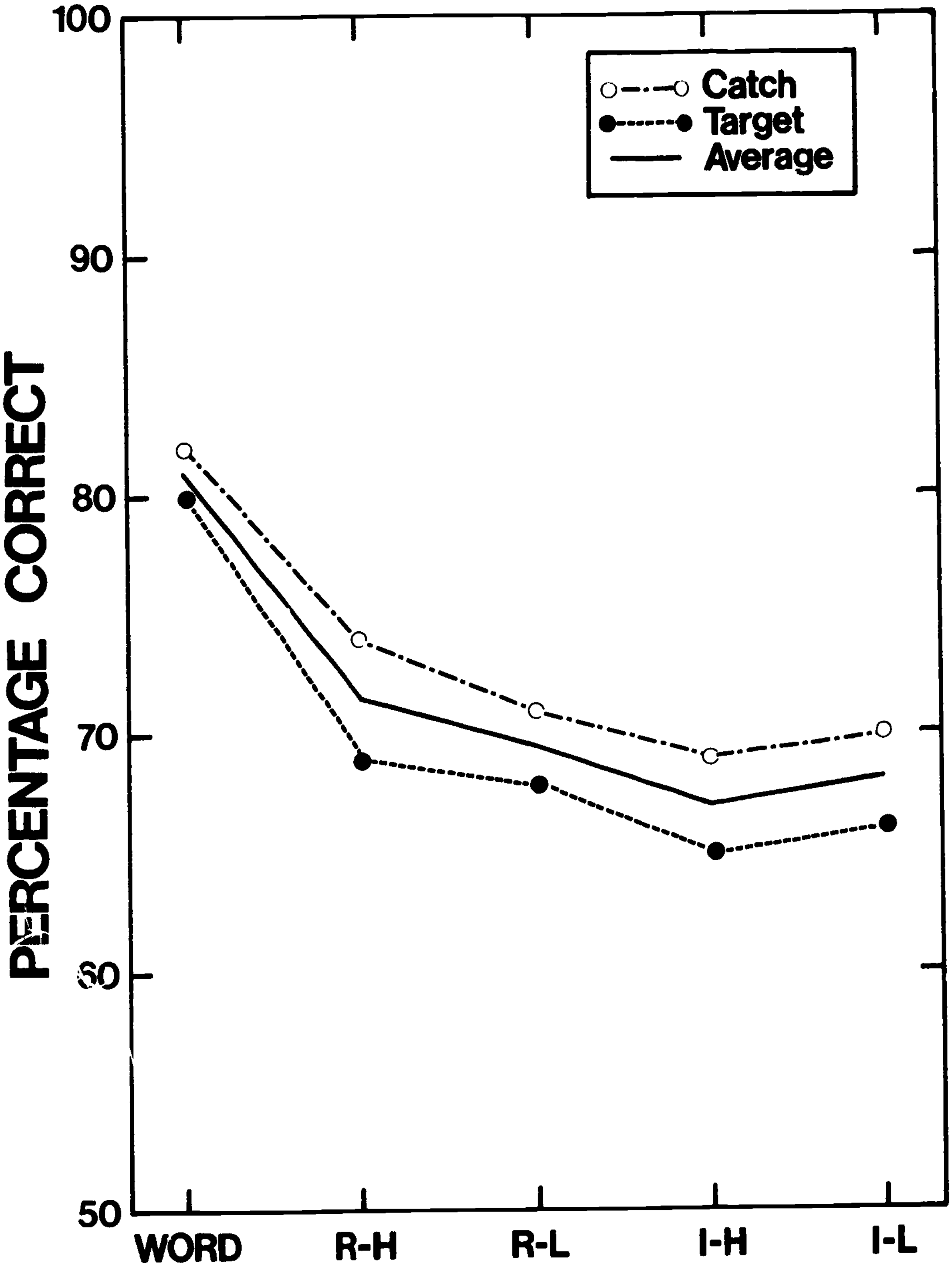



Figure 17. Percentage correct as a function of display type for target and catch trials in Experiment 5.

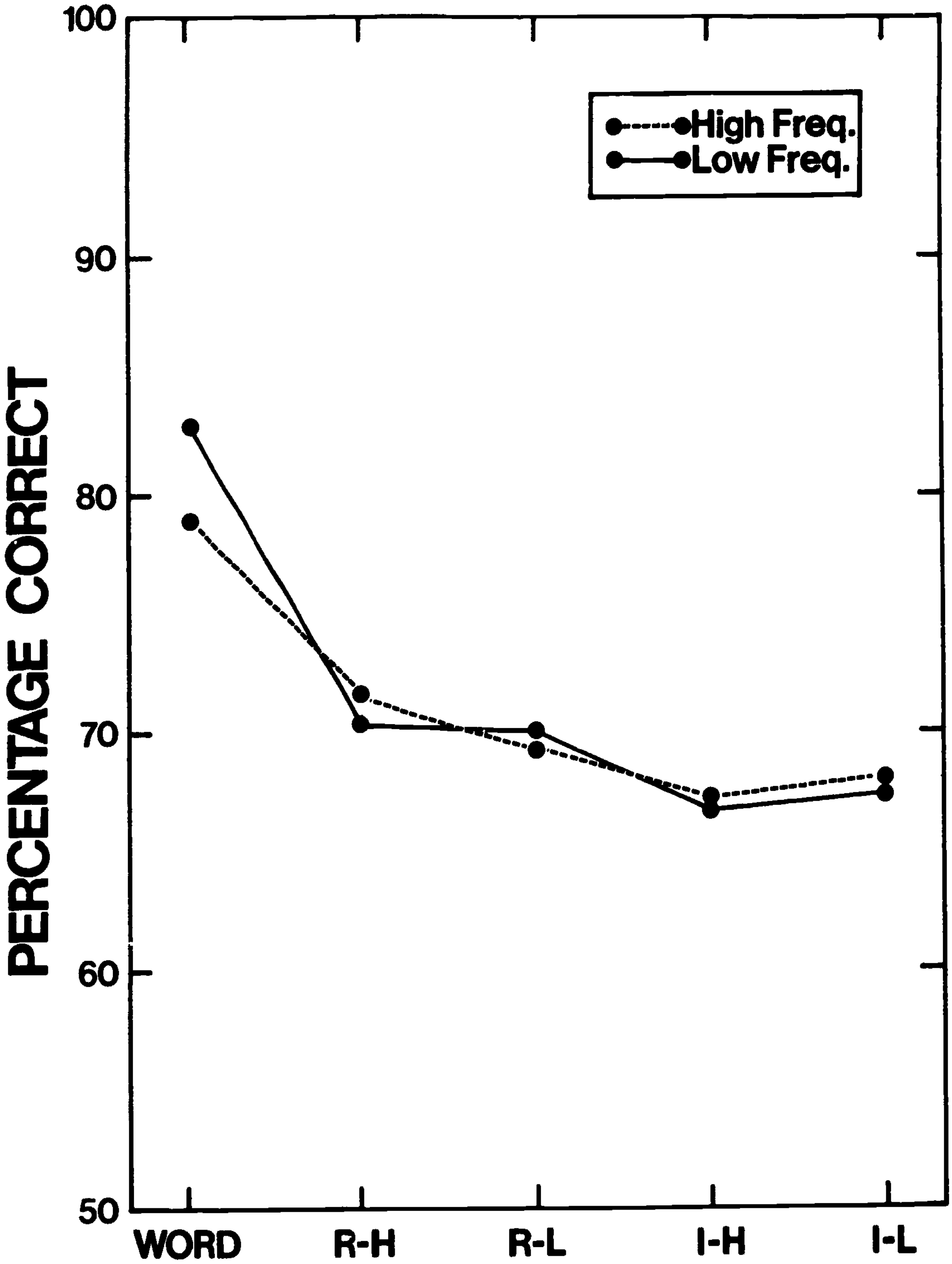



Figure 18. Percentage correct as a function of display type for items corresponding to high and low word frequency in Experiment 5.

Table 6
Correlations of Several Predictor Variables with Overall Accuracy Performance in Experiment 5.

| | |
|---|---|
| Single letter | |
| linear | .23 |
| log | .25 |
| Bigram | |
| linear | .35 |
| log | .43 |
| Trigram | |
| linear | .38 |
| log | .51 |
| Word frequency | |
| linear | .46 |
| log | .55 |
| Reguarlity Count(3) | .36 |

In a series of multiple regression analyses, the individual log counts at each position were treated as independent variables. The log single-letter counts at the sixth and first serial positions accounted for 7% of the variance. For log bigrams, the first, fifth, second, and fourth positions accounted for 22% of the variance. For log trigrams, the first and fourth positions accounted for 31%.

Summed log bigram frequency and Regularity(3) accounted for 24% of the variance. The partial correlations for summed log single-letter and trigram frequencies were -.08 and .28, respectively.

## Experiment 6

In Experiments 1-5, large effects were found for words as compared to the best anagrams (regular-high). One way to account for the effect is by the lexical status of the words. Since words are represented in the reader's lexicon, they may be retrieved on the basis of partial visual information. For example, the partial information sho_l_ might lead to recognition of the word should. Lexical access would allow determination of the two unknown letters. On the other hand, the partial information shu_o_ can not access any lexical entry and the missing letters can not be determined. Consequently, on a word trial there is a better chance that all of the component letters will be available for comparison against the target letter. In contrast, the same partial information about an anagram will not lead to recognition of all of the letters in the test string. As a result, fewer letters of anagrams will be available for comparison against the target letter. This account is consistent with the model articulated in the Introduction; the secondary recognition process can lead to word recognition without complete recognition of all of the component letters.

A second explanation of the word advantage is that words differ from even the best anagrams with respect to sublexical orthographic structure. For example, the bigram frequency of the words in Experiments 3 and 4 averaged almost three log units more than that for the regular-high anagrams (see Figure 12). Perhaps accuracy was greater for words because words contained more frequent bigrams.

To choose between these two explanations in Experiment 6, the words of Experiments 3, 4, and 5 were replaced with regular anagrams which were matched with the words on log bigram frequency. If log bigram frequency was the basis of the word advantage, then a similar advantage should be observed for these regular-very high (R-VH) anagrams.

Method

Experiment 6 was conducted in the same manner as the previous experiments with adult subjects. Regular very high anagrams with similar log bigram frequencies to the words of Experiments 3 and 4 were used along with all the anagrams of Experiments 3 and 4. The summed bigram frequencies for the regular-very high anagrams were 14.940 and 13.407 respectively, almost identical to those of the words (see Figure 12). The regular-very high anagrams are listed in Appendix 4. The experiment was identical to Experiment 4 except that the regular-very high anagrams were used in place of the word items. Seven new subjects obtained from the same Introductory Psychology subject pool used in the previous experiments participated in exchange for course credit. They were informed that a target would occur on 50% of the trials and that none of the letter strings were words.

## Results

Figure 19 shows the differences among the five types of letter strings, $F$ (4, 24) = 3.3, $p < .05$. There was a 0.3% advantage of regular very-high anagrams over regular-high anagrams, $F$ (1, 6) < 1. Regular anagrams gave a 3.6% advantage over irregular anagrams, $F$ (1, 24) = 13.8, $p <$ .005. There was a -0.2% effect for log bigram frequency, $F$ (1, 6) < 1.

There was only a 3.0% advantage of catch over target trials, $F$ (1, 6) < 1, but this variable interacted with the type of letter string, $F$ (4, 24) = 3.3, $p < .05$. This test reflects the presence of 7.4% increase in accuracy from the worst to the best structured strings for target trials, but an absence of an effect of orthographic structure for catch trials (Figure 19).

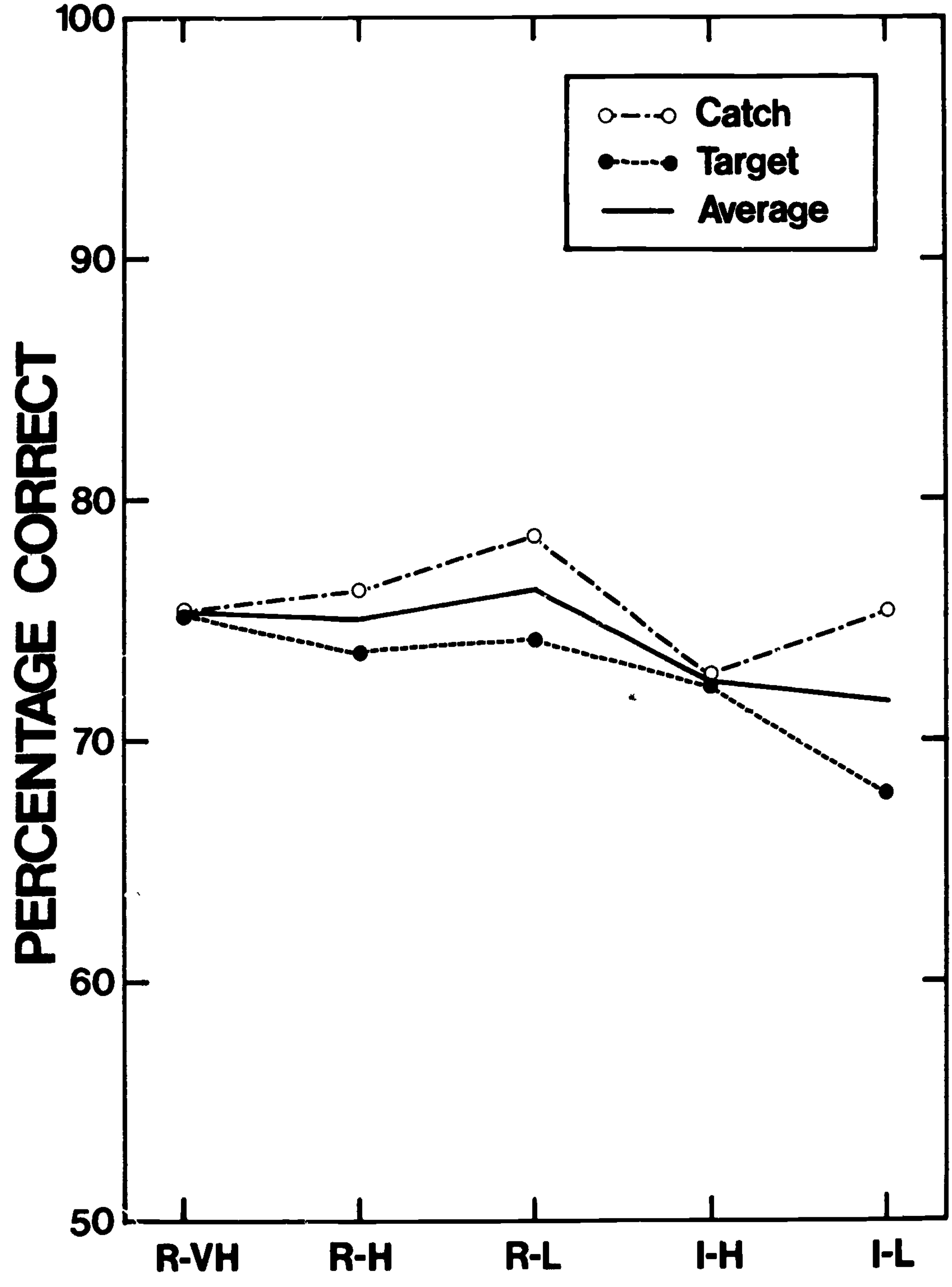



Figure 19. Percentage correct as a function of display type for target and catch trials in Experiment 6.

Figure 20 presents the average accuracy as a function of letter string type according to whether the items correspond to high or low word frequency. Neither the 0.6% difference nor the interaction with display type was statistically significant.

The results of Experiment 6 support the idea that lexical status makes a significant contribution to perceptual recognition in the target search task. The contribution of lexical status in the earlier experiments can not be attributed to sublexical orthographic structure differences in log bigram frequency. That is to say, the reader takes into account not only the frequency of occurrence of letter sequences and the regularity of these sequences, but also whether or not a particular sequence is represented in a word. Frequency and regularity allow well-structured anagrams to be better recognized than poorly structured anagrams and, in addition, lexical status allows a perceptual advantage of words over equally well-structured anagrams.

## Correlation Analysis

Table 7 presents the correlations of several variables with overall performance. The correlations, while attenuated, exhibit a pattern similar to the previous experiments. Log measures are better than linear measures; the regularity measure does about as well as the best frequency measure.

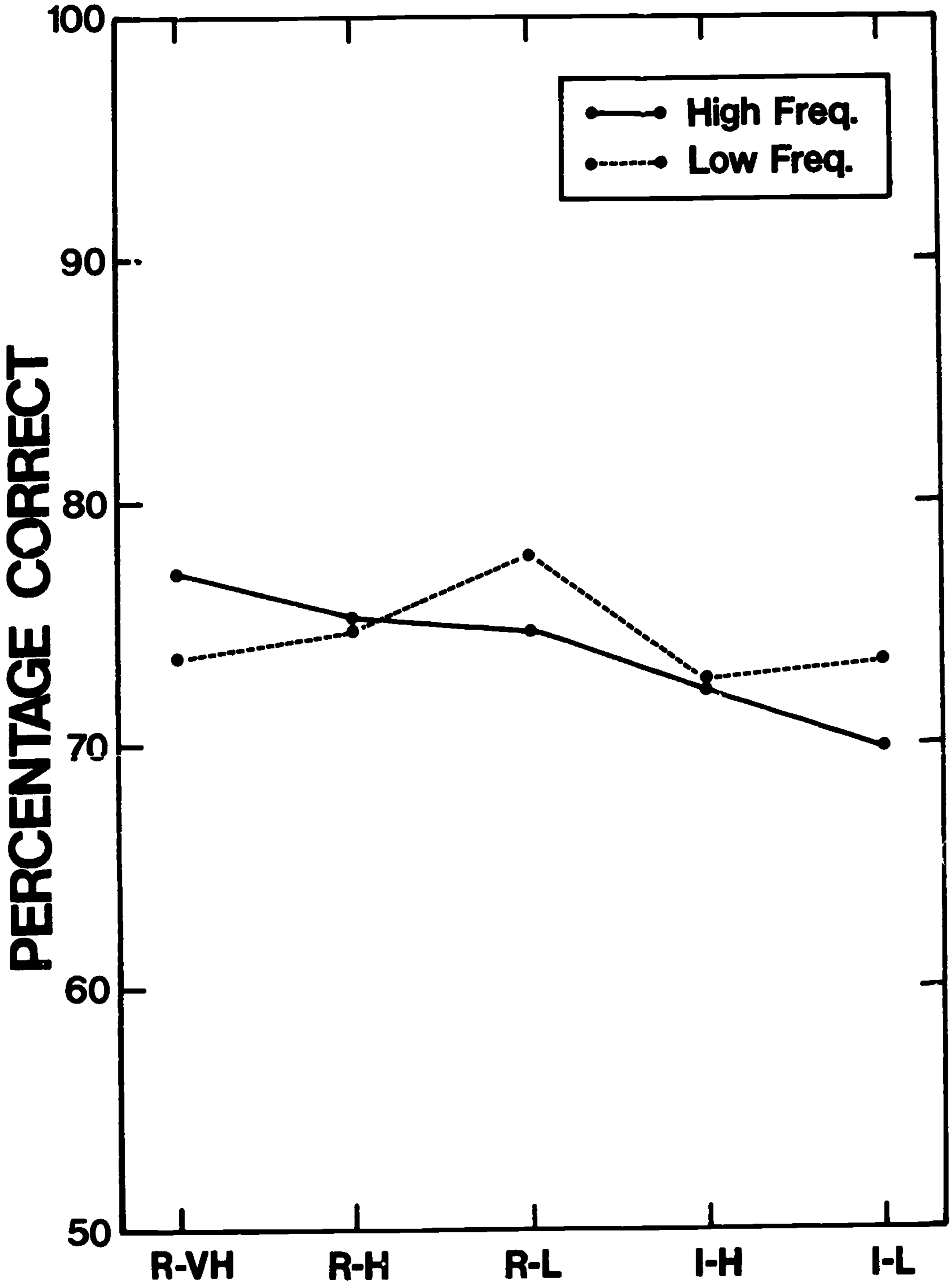



Figure 20. Percentage correct as a function of display type for items corresponding to high and low word frequency in Experiment 6.

Table 7

Correlations of Several Predictor

Variables with Overall Accuracy Performance

in Experiment 6.

| | |
|---|---|
| Single letter | |
| linear | .11 |
| log | .11 |
| Bigram | |
| linear | .05 |
| log | .11 |
| Trigram | |
| linear | .03 |
| log | .05 |
| Regularity Count(3) | -.14 |

### Multiple Regressions

Summed log bigram frequency and Regularity(3) accounted for 3% of the variance. The partial correlations for summed log single-letter and trigram frequencies were .01 and -.06, respectively.

## Experiment 7

Experiments 1-6 were not successful in choosing between frequency and regularity measures of orthographic structure. In a final evaluation of these measures, the perceptual recognition task was replicated with five display types. The display types were chosen to give a large range of regularity and frequency. The comparisons among display types and the post hoc correlations will be used to evaluate the relative contributions of lexical status, regularity, and frequency in perceptual recognition.

### Method

The R-VH anagrams from Experiment 5 and the words, regular-low anagrams, and irregular-high anagrams from Experiment 3 were used as items along with a new type of anagram that was both very irregular and very low in log bigram frequency. The very irregular, very low (VI-VL) anagrams mostly had three or four irregularities and average log bigram frequencies of 4.845 and 4.971 for the high and low word frequency items, respectively. The VI-VL anagrams are listed in Appendix 4. The procedure of Experiment 4 was replicated exactly. Eleven new subjects from the Introductory Psychology subject pool were used.

Results

As can be seen in Figure 21, accuracy uniformly increased with better structured letter strings; $F$ (4, 40) = 69.4, $p < .001$. Words had a 10.8% advantage over the regular-very high anagrams, $F$ (1, 40) = 15.9, $p < .001$. Regular-very high anagrams gave a performance advantage of 4.9% over regular-low anagrams, $F$ (1, 40) = 3.1, $p < .086$; a 7.6% advantage over irregular-high anagrams, $F$ (1, 40) = 7.9, $p < .01$; and a 8.9% advantage over very irregular-very low anagrams, $F$ (1, 40) = 10.7, $p < .005$.

The 6.9% advantage of catch over target trials was not significant, $F$ (1, 10) = 1.5, $p > .25$, and this difference did not interact with diplay type, $F < 1$.

Figure 22 reveals a 2.7% difference between levels of word frequency, $F$ (1, 10) = 32.17, $p < .001$, but the advantage of high word frequency occurred only for the words and the regular anagrams.

Correlations and Regressions

The correlations of several predictor variables with overall performance are presented in Table 8. As usual the log measures predict performance better than the linear measures. Bigrams and trigrams were similar in predictive

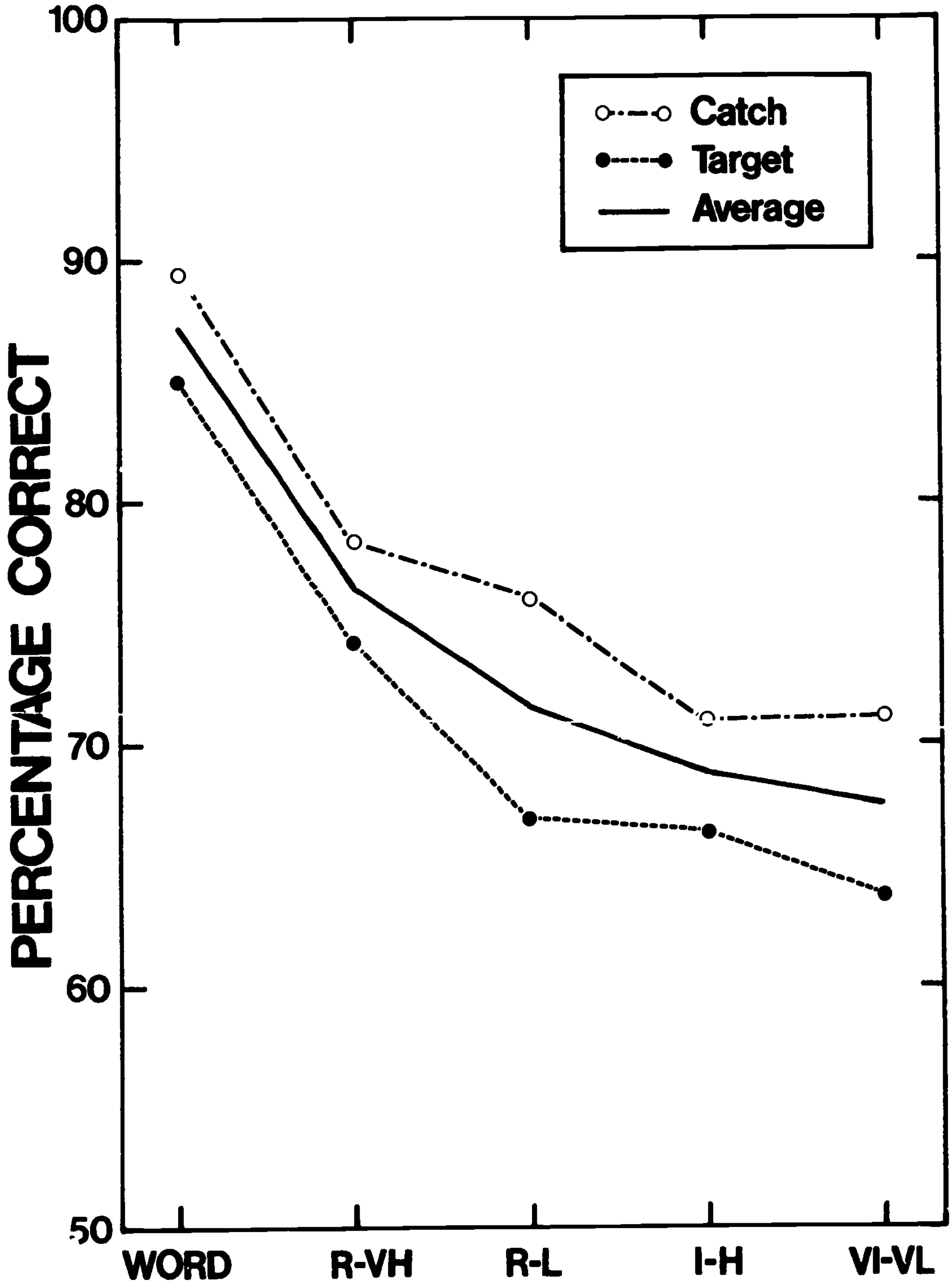



Figure 21. Percentage correct as a function of display type for target and catch trials in Experiment 7.

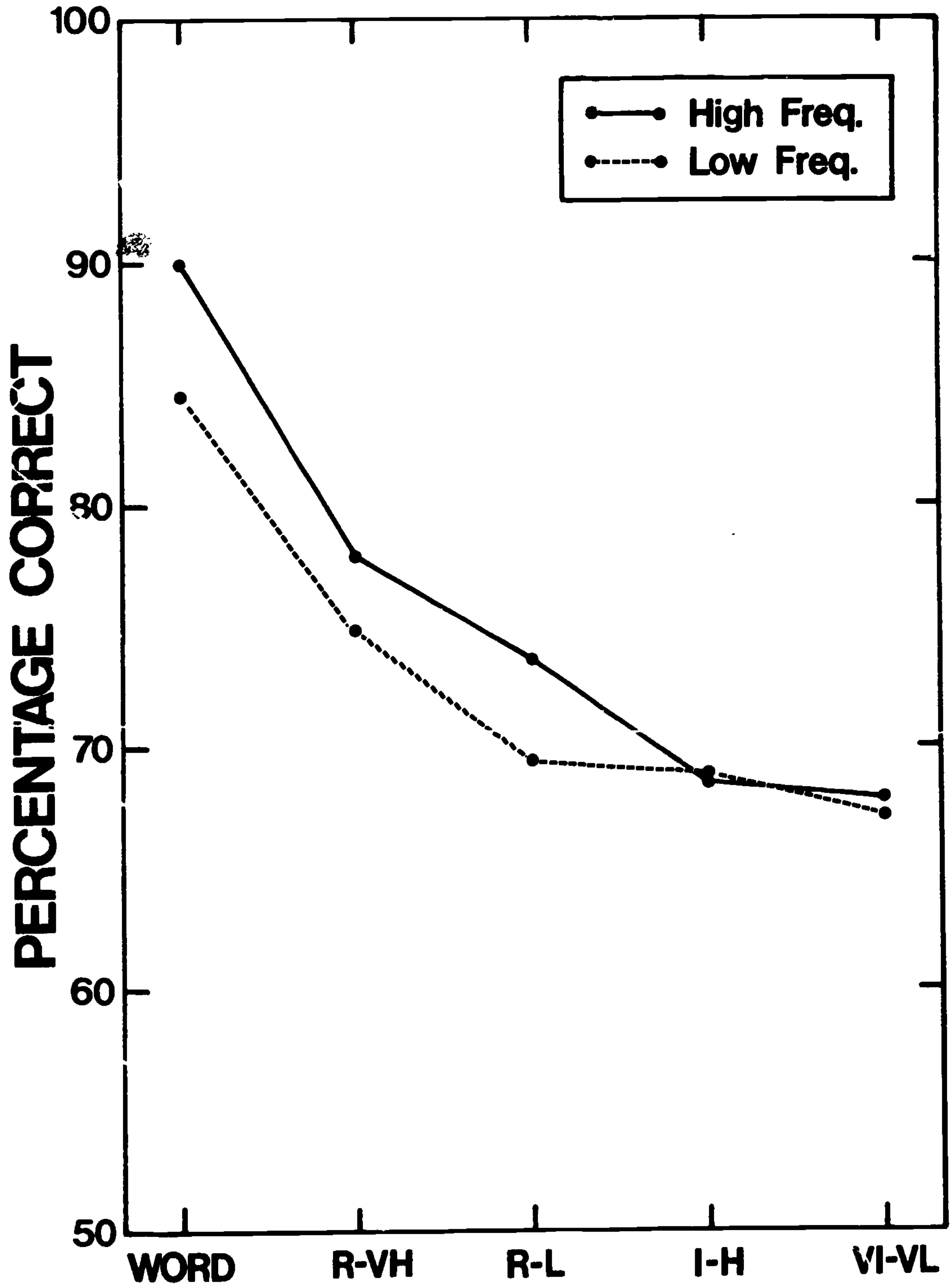



Figure 22. Percentage correct as a function of display type for items corresponding to high and low word frequency in Experiment 7

Table 8

Correlations of Several Predictor

Variables with Overall Accuracy in Experiment 7.

| | |
|---|---|
| Single letter | |
| linear | .35 |
| log | .37 |
| Bigram | |
| linear | .40 |
| log | .50 |
| Trigram | |
| linear | .41 |
| log | .59 |
| Word frequency | |
| linear | .38 |
| log | .54 |
| Regularity Count(3) | .44 |

ability. Log word frequency correlated .42 with overall performance, but also correlated .48 with summed log bigram frequency and .75 with summed log trigram frequency. Considered together, the results of Experiment 7 replicate previous experiments.

Summed log bigram frequency and Regularity(3) accounted for 27% of the variance. The partial correlations for log single-letter and log trigram frequencies were -.04 and .36, respectively.

## Experiment 8

The perceptual recognition task assesses the degree to which readers utilize orthographic structure in visual processing of letter strings. An overt judgment task has also been used to assess the degree to which this knowledge is available for a conscious report (Massaro et al., 1980; Rosinski & Wheeler, 1972). An overt judgment task is used in the present experiment to assess the degree to which regularity and frequency are consciously available. Subjects are given pairs of letter strings and asked to choose which letter string most resembles English spelling. Some subjects are instructed to base their decision on the frequency of occurrence of letter sequences in English spelling; other subjects are instructed to respond on the basis of the regularity of letter sequencing. The seven types of letter strings varying in lexical status, regularity, and log bigram frequency were paired with each other in the task. The degree to which subjects can follow instructions and discriminate among the types of items should reveal which aspect(s) of orthographic structure is (are) consciously available and capable of report.

## Method

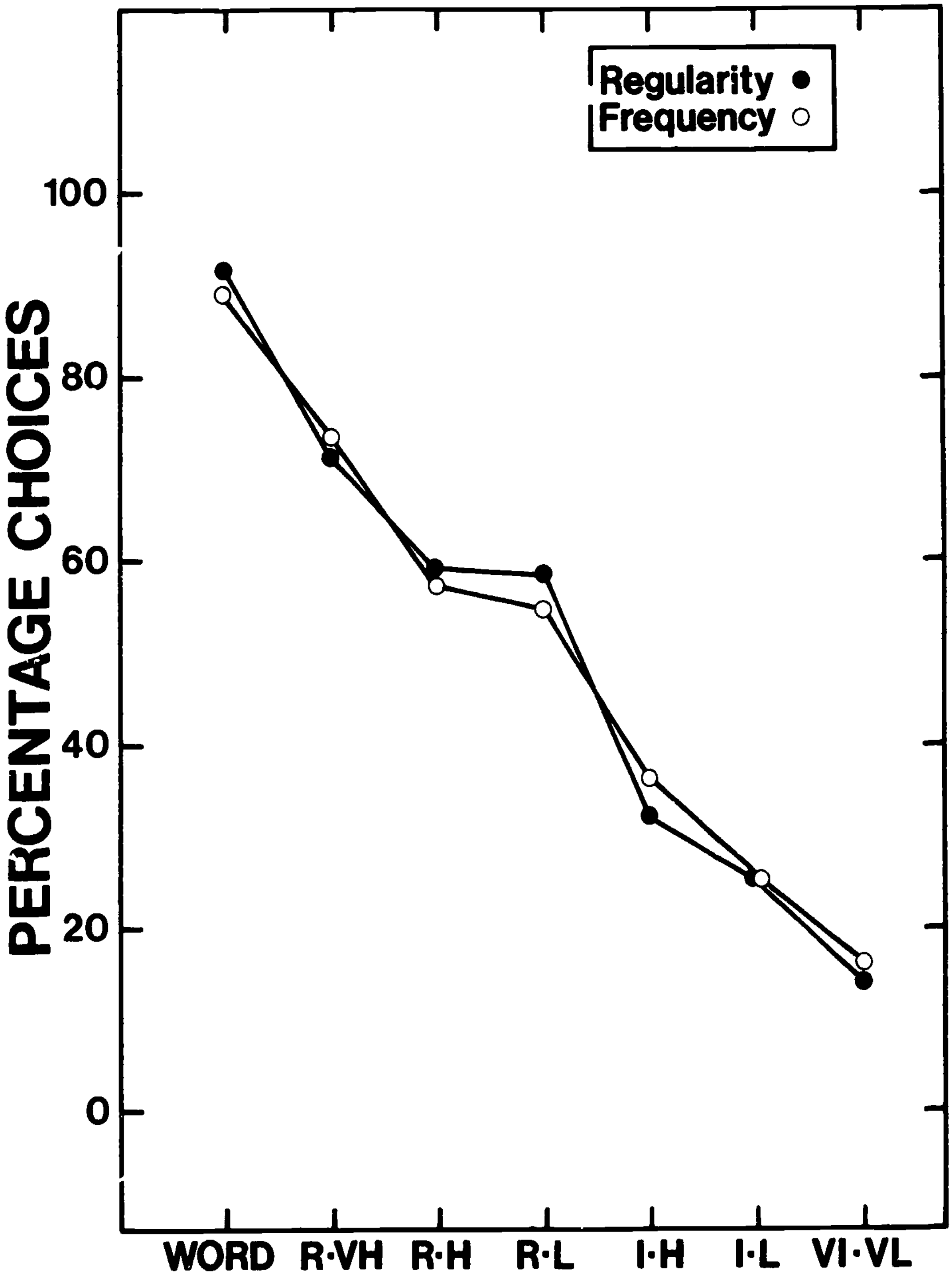
Subjects. Sixteen Introductory Psychology students who met the same requirements as in the first six experiments were used as subjects.

Stimuli and apparatus. The 280 letter strings represented all seven categories of items used in the previous experiments. Accordingly, 40 words and their corresponding R-H, R-L, I-H, and I-L anagrams of Experiment 3, 40 R-VH anagrams of Experiment 6, and 40 VI-VL anagrams of Experiment 7 were selected. The irregular items chosen from Experiment 3 had two irregularities. Seven categories, and allowing the two letter strings of a pair to be from the same category, result in 28 unique pairs of categories. These 28 pairs were sampled randomly without replacement in each block of 28 trials. The actual items from each of the categories for each pair were randomly selected with replacement for each group of subjects. Eventually, each subject was presented with 840 pairs for judgment, resulting in a total of 30 observations for each pair. The two strings of each pair were arranged side-by-side on the CRT. The horizontal visual angle of each letter string was 1.9

degrees with a 2.7 degree separation between strings. Depending on instructions, subjects selected the one of the two strings which was more regular or more frequent. Subjects indicated their choice by pressing one of two keys located beneath the string. Each trial began with a 250 msec fixation point followed by the two letter strings. The strings remained on the CRT until all the subjects responded or for a maximum of four seconds. The 840 pairs were presented in two sessions of 420 trials each. Each session lasted about 20 minutes. Of the 16 subjects, 8 were given the regularity instructions and 8 were given the frequency instructions. The exact instructions are given in Appendices 5 and 6, respectively.

## Results

For each subject, the proportion of times that each of the seven categories was chosen as most like English over the other six categories was computed. These proportions were entered into an analysis of variance with instructions, category type, and subjects as factors. Figure 23 presents the percentage of choices of most like English as a function of category and instructions. There was a large decrease in choices with decreases in orthographic structure, $\underline{F}$ (6, 84) = 351, $\underline{p} < .001$. However, instructions had no influence on performance and did not interact with structure, $\underline{F}$s $< 1$. All differences between adjacent categories in Figure 23 are statistically significant, except for the small difference




Figur 23. Average percentage choices of each of the disp: y types in the overt judgment task in Experiment 3.

between R-H and R-L items.

Table 9 presents the proportion of times each of the seven classes of items was chosen over the other six classes. Some effects of instructions not apparent in the average proportions shown in Figure 23 are seen in these results. The R-H items were picked over the R-VH items 39% of the time for regularity instructions and 25% of the time for frequency instructions. The three classes of irregular items (I-H, I-L, and VI-VL) were chosen an average of 13% of the time over the R-L items with regularity instructions and an average of 18% of the time with frequency instructions. Regular-very high items were chosen over words 17% of the time for regularity instructions and 25% of the time for frequency instructions. All of these results are consistent with the idea that frequency carries somewhat more weight in the overt judgment task with frequency instructions than with regularity instructions.

An analysis of variance also was conducted on the reaction times of the choice responses. Response type was included as a factor to assess the differences in reaction times between choosing a given category as most like English relative to the average reaction time for choosing the other six categories. Figure 24 presents the reaction times as a function of instructions, response type, and category. Overall reaction times were 232 msec longer for frequency than for regularity instructions, $\underline{F}$ (1, 14) = 6.9, $\underline{p} < .025$. Reaction times increased with decreasing orthographic

Table 9
The Proportion of Times the Row Item was Chosen Over the Column Item for Regularity and Frequency Instructions.

Regularity Instructions

| | Word | R-VH | R-H | R-L | I-H | I-L | VI-VL |
|---|---|---|---|---|---|---|---|
| Word | .55 | | | | | | |
| R-VH | .17 | .52 | | | | | |
| R-H | .12 | .39 | .50 | | | | |
| R-L | .15 | .32 | .50 | .51 | | | |
| I-H | .02 | .11 | .24 | .17 | .48 | | |
| I-L | .01 | .09 | .15 | .17 | .36 | .58 | |
| VI-VL | .00 | .02 | .09 | .06 | .28 | .30 | .53 |

Frequency Instructions

| | Word | R-VH | R-H | R-L | I-H | I-L | VI-VL |
|---|---|---|---|---|---|---|---|
| Word | .55 | | | | | | |
| R-VH | .25 | .50 | | | | | |
| R-H | .18 | .25 | .57 | | | | |
| R-L | .11 | .32 | .44 | .55 | | | |
| I-H | .07 | .14 | .27 | .25 | .50 | | |
| I-L | .02 | .09 | .17 | .20 | .38 | .52 | |
| VI-VL | .03 | .05 | .09 | .09 | .24 | .35 | .49 |

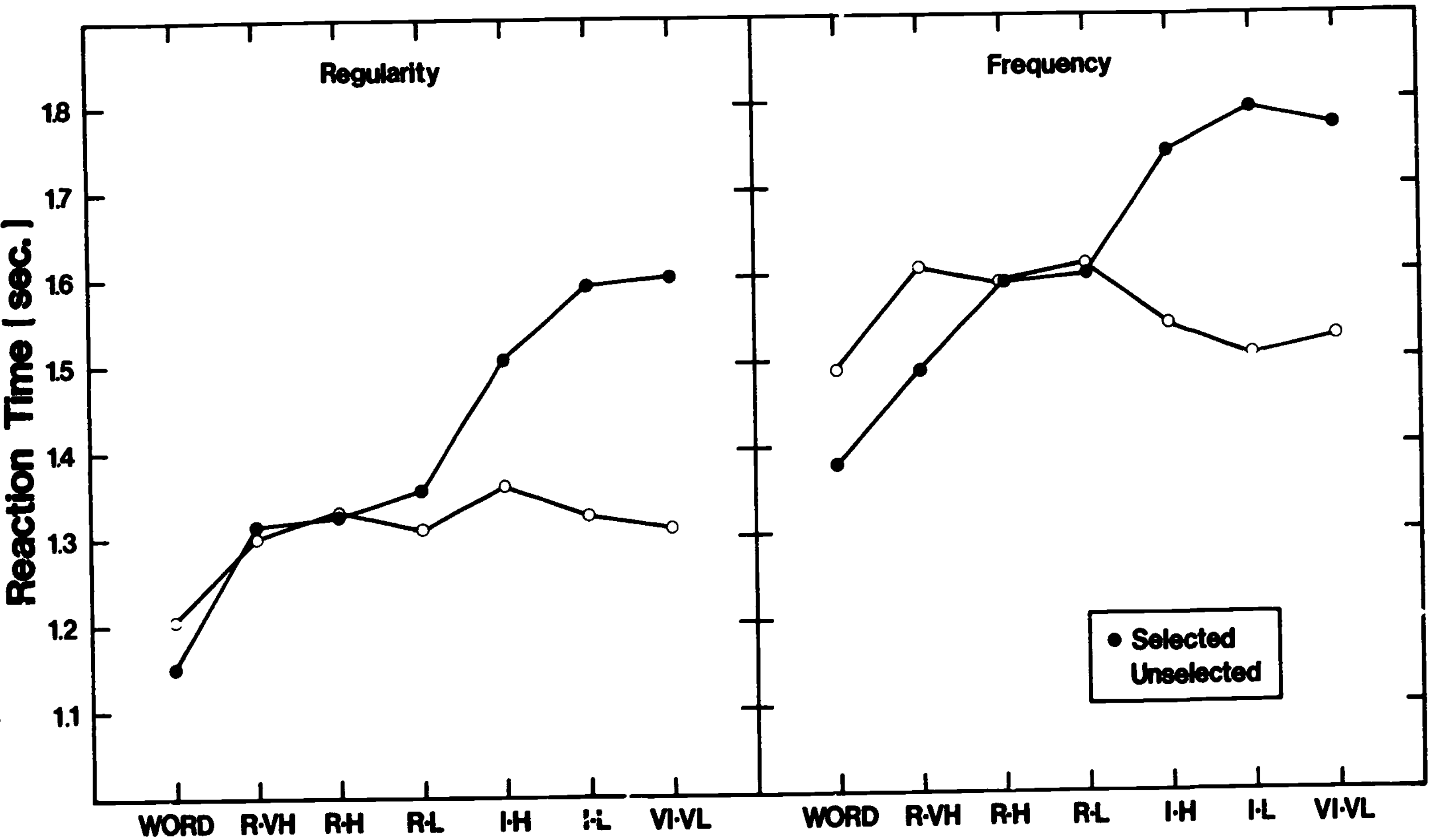



Figure 24. Average reaction times for choosing each of the display types (selected) and for choosing the alternative member of the pair (unselected) in Experiment 8.

structure, but only when that category was chosen as the item most like English, $F$ (6, 84) = 12.7 and 21.0, $p$s < .001.

A comparison between the perception task and overt judgment task shows that the latter is a much more sensitive measure of the reader's knowledge of orthographic structure. Subjects are able to discriminate among certain classes of items in the overt judgment task that are responded to equivalently in the perceptual accuracy task. For example, R-VH and R-H were differentiated in the overt judgment task but were responded to equivalently in the perceptual accuracy task of Experiment 6. The same was true of the I-H vs I-L and the I-H vs VI-VL contrasts. Other results were exactly parallel in the two tasks: Words have an advantage over regular items and regular items have an advantage over irregular items.

## Discussion

In summary, the orthogonal contrasts of lexical status, word frequency, position-sensitive frequency, and regularity provide evidence for the following conclusions. Lexical status provides a perceptual advantage of words over equally well-structured anagrams. Word frequency appears to add very little, if anything, beyond that accounted for by lexical status. Regular anagrams are recognized significantly better than irregular anagrams whereas log bigram freqeuncy has no influence when regularity is controlled. However, the post hoc correlations of these measures of orthographic structure with perceptual recognition of each of the 400 test items complicate these conclusions somewhat. Log bigram frequency usually correlates positively with performance on letter strings even after the influence of lexical status and regularity has been removed. In this regard, frequency measures allow a fine-grained description of orthographic structure that provides a good index of performance on individual letter strings. The binary classification of lexical status and the small range of the number of irregularities limit the usefulness of these measures as descriptions of a relatively continuous variation in orthographic structure. Some frequency weighting of regularity description might lead to a improved measure of structure. Until such a description is developed, it appears necessary to include lexical status, frequency, and regularity to account for those components of orthographic structure that are psychologically real. The results of the present studies also are relevant to previous studies of orthographic structure.

The utilization of orthographic structure in reading was first studied by Miller, Bruner, and Postman (1954), who had subjects reproduce letter sequences presented tachistoscopically. The strings were all eight letters and corresponded to different approximations to English based on Shannon's (1948, 1951) algorithms. Miller et al. found that performance improved with better approximations to English.

By correcting for the relative information per letter in the strings, the amount of information transmitted was shown to be equal for the various approximations. This result is consistent with more recent empirical and theoretical work demonstrating that orthographic structure provides an independent source of information to the reader (Massaro, 1979a, b; Massaro et al. 1980). In fact, the approximation-to-English algorithms may be viewed as early descriptions of orthographic structure. Accordingly, the more recent studies replicate and extend the Miller et al. results. The major advances in the recent studies are the more precise descriptions of structure (see Massaro et al., 1980, Chapter 3) and the quantitative modeling of the processes by which visual information combines with structure during word recognition (Massaro, 1979a, b).

Related research by Gibson and her colleagues evaluated the role of word length and pronounceability in a full report of letter strings by both hearing and deaf readers (Gibson, Pick, Osser, & Hammond, 1962; Gibson, Shurcliff, & Yonas, 1970). They found that the number of errors increased with increases in word length and decreased with increases in pronounceability. In the post hoc regression analyses, word length accounted for 72% of the variance and pronounceability accounted for another 15%. Position-sensitive and word length specific bigram and trigram frequencies were significantly poorer predictors of performance. However, these counts can not be used in any straightforward manner for items of various letter lengths. Words of different lengths do not occur with equal frequency and the less frequent word lengths will naturally have bigrams and trigrams with smaller counts. Therefore, this comparison can not be considered an adequate test between pronounceability and frequency measures of orthographic structure. The finding that deaf and hearing readers were influenced similarly by pronounceability argues that orthographic structure rather than pronounceability is the important structural variable.

Manelis (1974) found an advantage of four-letter words over pseudowords in tachistoscopic recognition, but failed to find a significant correlation between recognition and summed linear bigram and trigram frequencies, as measured by Mayzner and Tresselt (1965) and Mayzner, Tresselt and Wolin, (1965). In a more recent study, McClelland and Johnston (1977) independently varied position-sensitive bigram frequency and lexical identity in four-letter strings in a Reicher-Wheeler forced-choice task (Reicher, 1969; Wheeler, 1970). In addition, a full report of the four letters either preceded or followed the forced-choice response. The forced-choice responses revealed no effect of either bigram frequency or an advantage of words over orthographically regular pseudowords. Forced-choice responses also showed a 13% advantage of words and pseudowords over single letters, replicating the word-letter difference of Reicher (1969). The full report score replicated the absence of a bigram frequency effect found for the forced-choice task, but showed an advantage of words over pseudowords. Also, the full report score revealed a large word frequency effect. In post hoc analyses, McClelland and Johnston report that bigram frequency did not correlate with perceptual accuracy whereas, single-letter position frequency was highly correlated with accuracy.

Using a different task, Henderson and Chard (1980) presented items either high or low in both position-sensitive single-letter and bigram frequencies in a lexical decision task. Their results indicate that second and fourth graders were faster in rejecting low-frequency than high-frequency six-letter nonwords. In a related study, Bouwhis (Note 3) found that single-letter positional frequency correlated with lexical decisions for three-letter items in Dutch. Reaction times to words decreased while reaction times to pseudowords increased with increases in single-letter frequency. Similarly, subjects tended to respond "word" more often to both words and pseudowords if the items were of high single-letter frequency. In contrast, these correlations were considerably diminished when bigram positional frequency was used as the predictor variable. Bouwhis' results when compared with those of Henderson and Chard (1980), imply that the power of the bigram frequency measure with our six-letter items may not generalize completely to smaller letter-string lengths. That is, bigram frequency appears to have more predictive power than single-letter frequency when the items are six letters in length, but the reverse is indicated when the items are three or four letters in length. However, such a conclusion is tenuous for two reasons. First, single-letter and bigrams measures are highly correlated even for small letter-string lengths. Second, experiments demonstrating the predictive power of single-letter frequencies have used linear rather than log counts. Since log counts are uniformly better predictors of the data, it will first have to be shown that log counts do not change the relative power of the two frequency measures. Of the several studies (McClelland & Johnston, 1977; Bouwhis, Note 3) investigating the relative contributions of single-letter and bigram frequencies, only the present studies directly compare linear and log single-letter and bigram counts. The present studies found that log counts are consistently better than linear counts and that bigram counts are better than single-letter counts.

In the first of two experiments investigating other structural variables, Spoehr (1978) showed that report accuracy in the Reicher-Wheeler task was lower for five-letter, one-syllable strings made up of five phonemes than those made up of four phonemes. Performance for words such as _thump_ and pseudowords such as _sherk_ averaged 76% correct whereas, performance was 4% worse for words such as _spank_ and pseudowords such as _crost_. Average accuracy on words was 7% greater than on pseudowords. In the second experiment, two-syllable words were recognized 13% more poorly than one-syllable words when phoneme length was equated. Although Spoehr (1978) showed that position-sensitive bigram frequency of the letters could not account for the observed differences, log counts might have been more appropriate. Furthermore, since our counts were derived from the considerably larger Kucera and Francis (1967) corpus, they are likely more reliable than the Mayzner and Tresselt (1965) counts that Spoehr employed. Accordingly, Spoehr's results are not necessarily inconsistent with the present results.

In conclusion, a number of recent experiments have failed to find significant effects of position sensitive bigram frequency in the perceptual recognition of letter strings. However, these studies all used linear rather than log counts and we have found much larger effects with the log counts. Linear and log counts correlate .84 and .66 for single letter and bigram position sensitive counts for four letter words, .86 and .76 for five letter words and .85 and .76 for six letter words in the Kucera-Francis corpus. Therefore, there is sufficient room for improvement of log over linear counts in accounting for perceptual recognition. Previous studies and analyses of completed experiments should evaluate log as well as linear counts to provide a sufficient test of frequency measures of perceptual recognition.

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# Appendix 1

The 200 stimulus item from Experiment 1. The items listed are in columns accordi`q to type, where W=word; R-H=regular, high; I-H=irregular, ı _n; R-L-regular, low; and I-L=irregular, low. Each row contains a word and the four anagrams generated from it. The number beside each item indicates the number of orthographic irregularities that the item contains as determined by the rules in Table 2. The items are also grouped in high and low Kucera and Francis (1967) word frequency.

## High Word Frequency

| W | | R-H | | R-L | | I-H | | I-L | |
|---|---|---|---|---|---|---|---|---|---|
| almost | 0 | latoms | 0 | amtols | 1 | stlmao | 4 | mltsoa | 4 |
| around | 1 | adourn | 1 | orudan | 1 | nroudg | 2 | ndauor | 2 |
| course | 0 | coures | 0 | rosuce | 0 | csouer | 2 | reucso | 1 |
| during | 0 | nurdig | 0 | nirdug | 0 | nurdgi | 1 | grdniu | 4 |
| itself | 0 | fiselt | 0 | fliste | 0 | eistlf | 1 | fetsli | 1 |
| longer | 0 | roleng | 0 | nogerl | 0 | nlgoer | 3 | grlneo | 2 |
| making | 0 | mikang | 0 | gimank | 0 | agkinm | 1 | gmkian | 2 |
| modern | 0 | remond | 0 | noderm | 0 | dnmoer | 3 | monrde | 1 |
| mother | 0 | hemort | 0 | rhetom | 0 | ormteh | 1 | tmoreh | 2 |
| nature | 0 | tanure | 0 | nutear | 0 | unrtea | 2 | ntreua | 2 |
| number | 0 | rumben | 0 | runemb | 0 | bemrnu | 2 | brnemu | 2 |
| others | 0 | horest | 0 | rohets | 0 | strheo | 2 | etrsoh | 2 |
| period | 1 | ipoder | 1 | iperod | 1 | dpoier | 2 | opdrei | 1 |
| public | 0 | piculb | 0 | cipbul | 0 | licpbu | 2 | pbiclu | 2 |
| reason | 0 | sonare | 0 | ronase | 0 | nroaes | 2 | rsaneo | 2 |
| second | 0 | snoced | 0 | cenods | 0 | oscned | 1 | osndce | 2 |
| should | 0 | hoduls | 0 | hudols | 0 | lsoudh | 3 | lohdsu | 2 |
| social | 0 | sicoal | 0 | ocasil | 1 | calsoi | 1 | oaiscl | 2 |
| toward | 0 | wartod | 0 | drawot | 0 | wtaord | 2 | rtwado | 2 |
| turned | 0 | rundet | 0 | endrut | 0 | retdnu | 2 | unedtr | 1 |

## Low Word Frequency

| W | | R-H | | R-L | | I-H | | I-L | |
|---|---|---|---|---|---|---|---|---|---|
| cinema | 1 | manice | 0 | micean | 0 | caeinm | 3 | ieacmn | 3 |
| depict | 0 | pedict | 0 | pedcit | 0 | cpdtei | 4 | eitcpd | 2 |
| divers | 0 | sirved | 0 | vedsir | 0 | svried | 2 | vdeisr | 2 |
| eskimo | 1 | simoke | 0 | esikom | 0 | seiokm | 2 | oieskm | 2 |
| glazes | 0 | zagles | 0 | glezas | 0 | alzges | 1 | zslega | 2 |
| golfer | 0 | glofer | 0 | frelog | 0 | flgoer | 2 | feorlg | 2 |
| gulped | 0 | lupged | 0 | pledug | 0 | plgued | 1 | lpdgeu | 4 |
| hurdle | 0 | hulder | 0 | helrud | 0 | rlhued | 2 | ldeurh | 3 |
| icebox | 0 | coxibe | 0 | ecobix | 0 | xeoicb | 2 | ebxcio | 4 |
| inlets | 0 | linets | 0 | tensil | 0 | eintls | 1 | ltsnei | 3 |
| lavish | 0 | valish | 0 | hivals | 0 | hsvial | 2 | asvihl | 1 |
| milder | 0 | limder | 0 | ledrim | 0 | ilrmed | 1 | mreidl | 2 |
| mystic | 0 | symict | 0 | cimsty | 0 | stciym | 2 | yimcst | 1 |
| nectar | 0 | nacter | 0 | cetran | 0 | acnter | 1 | crtnea | 3 |
| neural | 0 | lanure | 0 | nulear | 0 | reanlu | 1 | lnareu | 2 |
| novice | 0 | vocine | 0 | nivoce | 0 | oecinv | 3 | oinecv | 1 |
| somber | 0 | morebs | 0 | romebs | 0 | msbore | 1 | bmreos | 2 |
| spiced | 0 | pisced | 0 | cipeds | 0 | spcied | 1 | cspdei | 3 |
| tripod | 0 | podirt | 0 | pidrot | 0 | ptrido | 2 | rotpdi | 2 |
| tumble | 0 | beltum | 0 | lutmeb | 0 | betlmu | 2 | tlmbue | 3 |

Appendix 2

The 200 stimulus items from Experiment 2. The number of irregularities is indicated beside each item.

High Word Frequency

| W | R-H | R-L | I-H | I-L |
|---|---|---|---|---|
| amount 1 | umaton 0 | tunoam 0 | mtouna 2 | ntomau 2 |
| answer 0 | wranes 0 | erswan 0 | wsnaer 2 | nwaesr 3 |
| direct 0 | decirt 0 | tedcir 0 | cdrtei 3 | tdrcie 2 |
| forces 0 | scofer 0 | fescor 0 | sfcoer 3 | oercfs 4 |
| friend 0 | nefird 0 | edfirn 0 | dfinre 1 | fenrdi 2 |
| ground 0 | udrong 1 | gonrud 0 | ourdng 1 | ndrugo 2 |
| island 0 | siland 0 | slidan 0 | sdainl 2 | saidnl 2 |
| method 0 | thomed 0 | hedmot 0 | omhted 1 | teohdm 2 |
| myself 0 | mesfly 0 | flesmy 0 | ylmfes 3 | eyslmf 3 |
| nearly 0 | renaly 0 | leynar 0 | ynlaer 2 | ryaenl 3 |
| person 0 | prescn 0 | roneps 0 | npsore 2 | pnseor 2 |
| points 0 | pisont 0 | snipot 0 | itpson 1 | tnposi 3 |
| police 0 | picole 0 | icopel 0 | oicple 0 | ieopcl 3 |
| showed 0 | howeds 0 | edwhos 0 | shdweo 3 | wsohde 2 |
| simply 0 | limspy 0 | sylmip 0 | ysmpli 3 | syilpm 3 |
| simple 0 | miples 0 | lepsim 0 | pmiles 1 | pslmei 3 |
| single 0 | legins 0 | glinse 0 | lniges 1 | insegl 1 |
| square 0 | quares 0 | quarse 0 | uqsaer 2 | arqseu 2 |
| values 0 | seavul 0 | lavuse 0 | sealuv 1 | seuvla 1 |
| volume 0 | movule 0 | evomul 0 | meoulv 3 | evomlu 1 |

## Low Word Frequency

| W | | R-H | | R-L | | I-H | | I-L | |
|---|---|---|---|---|---|---|---|---|---|
| donate | 0 | natode | 0 | odetan | 0 | oeandt | 4 | toaedn | 3 |
| digest | 0 | sigdet | 0 | tedigs | 0 | sdgtei | 4 | tgsdei | 4 |
| delays | 0 | dealys | 0 | eldsay | 0 | ydlaes | 2 | lyeasd | 2 |
| dainty | 0 | natidy | 0 | yidtan | 0 | iatynd | 1 | tndaiy | 3 |
| hounds | 0 | shodun | 0 | snohud | 0 | dnouhs | 2 | nuohsd | 2 |
| invest | 0 | vitens | 0 | snevit | 0 | tseinv | 3 | svneit | 2 |
| magnet | 0 | gamten | 0 | tegnam | 0 | mtaeng | 2 | tgenma | 2 |
| oceans | 0 | cosane | 0 | ecosan | 0 | aecosn | 2 | cneaso | 2 |
| outcry | 0 | octury | 0 | rutcoy | 0 | ycoutr | 2 | ycrtuo | 3 |
| packet | 0 | catkep | 0 | kepcat | 0 | kpatec | 1 | aktpec | 1 |
| pelvic | 0 | pecvil | 0 | vepcil | 0 | iecplv | 3 | ielvpc | 2 |
| pigeon | 0 | gopine | 0 | ginope | 0 | eiopng | 2 | eigopn | 1 |
| punish | 0 | hupins | 0 | hunsip | 0 | sphinu | 1 | nhsipu | 3 |
| rodent | 0 | dentor | 0 | tenrod | 0 | rndteo | 4 | netrdo | 2 |
| salute | 0 | tasule | 0 | sulate | 0 | salteu | 1 | tseual | 2 |
| socket | 0 | cosket | 0 | tesock | 0 | sckteo | 3 | ktceso | 3 |
| tropic | 0 | picort | 0 | ripcot | 0 | cotipr | 1 | trpcio | 3 |
| unlock | 0 | luckon | 0 | olnuck | 0 | lcoukn | 2 | clnkou | 3 |
| unwise | 0 | wusine | 0 | nuwise | 0 | uesinw | 2 | seuwni | 1 |
| widest | 0 | ditsew | 0 | wedsit | 0 | stdiew | 1 | wdtesi | 3 |

# Appendix 3

The 400 items used in Experiments 3 and 4 along with percentage correct for each experiment (E3, E4) summed log single-letter frequency (SL), summed log bigram frequency (BI), summed log trigram frequency (TRI), log word frequency (FREQ) and number of irregularities (I).

## High Word Frequency

### Words

| ITEM | E3 | E4 | SL | BI | TRI | FREQ | I |
|---|---|---|---|---|---|---|---|
| almost | 97.2 | 96.9 | 21.87 | 14.47 | 10.56 | 2.64 | 1 |
| around | 91.7 | 84.4 | 23.07 | 15.92 | 11.54 | 2.75 | 1 |
| behind | 100.0 | 93.7 | 23.04 | 15.39 | 9.75 | 2.41 | 0 |
| beyond | 94.4 | 96.9 | 22.67 | 14.62 | 9.72 | 2.24 | 0 |
| bridge | 94.4 | 90.6 | 21.94 | 13.05 | 8.58 | 1.99 | 0 |
| charge | 94.4 | 93.7 | 22.28 | 14.51 | 9.61 | 2.09 | 0 |
| coming | 97.2 | 87.5 | 22.94 | 16.19 | 10.80 | 2.24 | 0 |
| county | 88.9 | 93.7 | 22.19 | 14.83 | 10.16 | 2.19 | 0 |
| course | 86.1 | 84.4 | 22.38 | 15.16 | 11.14 | 2.67 | 0 |
| design | 97.2 | 84.4 | 22.46 | 13.17 | 9.04 | 2.06 | 0 |
| direct | 91.7 | 96.9 | 22.58 | 14.09 | 9.16 | 2.11 | 0 |
| during | 88.9 | 93.7 | 22.69 | 16.44 | 12.05 | 2.77 | 0 |
| family | 88.9 | 87.5 | 22.97 | 14.87 | 10.33 | 2.52 | 0 |
| friend | 100.0 | 90.6 | 22.84 | 14.61 | 9.28 | 2.12 | 0 |
| ground | 94.4 | 96.9 | 22.56 | 15.78 | 11.46 | 2.27 | 0 |
| having | 83.3 | 93.7 | 22.12 | 15.78 | 11.43 | 2.45 | 0 |
| longer | 100.0 | 84.4 | 22.96 | 15.67 | 10.20 | 2.29 | 0 |
| making | 88.9 | 75.0 | 22.09 | 15.78 | 11.36 | 2.41 | 0 |
| market | 91.7 | 96.9 | 23.19 | 15.52 | 10.40 | 2.19 | 0 |
| modern | 91.7 | 87.5 | 22.33 | 14.40 | 9.64 | 2.30 | 0 |
| nature | 94.4 | 81.2 | 22.89 | 15.31 | 10.63 | 2.28 | 0 |
| number | 94.4 | 96.9 | 22.01 | 15.20 | 11.07 | 2.67 | 0 |
| others | 91.7 | 87.5 | 21.50 | 13.91 | 10.51 | 2.51 | 1 |
| period | 94.4 | 87.5 | 23.76 | 15.25 | 10.21 | 2.42 | 0 |
| person | 97.2 | 90.6 | 22.77 | 15.15 | 10.20 | 2.24 | 0 |
| placed | 94.4 | 93.7 | 22.70 | 15.22 | 9.99 | 2.10 | 0 |
| places | 94.4 | 84.4 | 22.61 | 14.86 | 10.30 | 2.00 | 0 |
| points | 91.7 | 96.9 | 22.63 | 14.47 | 9.48 | 2.16 | 0 |
| public | 91.7 | 84.4 | 20.40 | 13.94 | 10.57 | 2.64 | 0 |
| raised | 88.9 | 78.1 | 23.25 | 15.27 | 9.22 | 2.00 | 0 |
| result | 94.4 | 90.6 | 23.02 | 14.56 | 9.74 | 2.39 | 0 |
| should | 100.0 | 93.7 | 23.33 | 15.98 | 12.07 | 2.95 | 0 |
| simple | 91.7 | 93.7 | 22.94 | 15.01 | 10.78 | 2.21 | 0 |
| taking | 94.4 | 87.5 | 22.01 | 15.32 | 11.16 | 2.24 | 0 |
| toward | 88.9 | 87.5 | 22.32 | 14.41 | 10.78 | 2.59 | 0 |
| turned | 97.2 | 87.5 | 23.42 | 15.57 | 10.74 | 2.51 | 0 |
| volume | 97.2 | 100.0 | 21.70 | 13.59 | 9.11 | 2.13 | 0 |
| walked | 94.4 | 87.5 | 22.91 | 15.70 | 10.18 | 2.20 | 0 |
| wanted | 88.9 | 93.7 | 23.50 | 16.65 | 10.70 | 2.35 | 0 |
| worked | 91.7 | 84.4 | 23.22 | 15.67 | 10.33 | 2.11 | 0 |

## Regular-High

| ITEM | E3 | E4 | SL | BI | TRI | FREQ | I |
|---|---|---|---|---|---|---|---|
| olmast | 77.8 | 81.2 | 21.12 | 11.72 | 1.04 | 0.00 | 1 |
| anudor | 75.0 | 65.6 | 21.76 | 10.60 | 0.00 | 0.00 | 1 |
| hibend | 72.2 | 50.0 | 22.19 | 12.78 | 3.88 | 0.00 | 0 |
| dobney | 66.7 | 78.1 | 22.36 | 10.39 | 1.30 | 0.00 | 0 |
| gedirb | 63.9 | 59.4 | 20.03 | 11.41 | 1.65 | 0.00 | 0 |
| hacerg | 58.3 | 65.6 | 22.23 | 11.45 | 0.95 | 0.00 | 0 |
| cogmin | 75.0 | 71.9 | 21.60 | 9.52 | 0.00 | 0.00 | 0 |
| coyunt | 75.0 | 62.5 | 22.35 | 10.73 | 2.24 | 0.00 | 0 |
| coruse | 33.3 | 78.1 | 23.10 | 13.75 | 5.42 | 0.00 | 0 |
| gineds | 69.4 | 65.6 | 21.79 | 12.09 | 3.03 | 0.00 | 0 |
| cirted | 86.1 | 75.0 | 24.00 | 14.87 | 8.06 | 0.00 | 0 |
| rignud | 69.4 | 84.4 | 21.53 | 9.93 | 3.91 | 0.00 | 0 |
| mayfil | 80.6 | 68.7 | 20.16 | 9.33 | 0.00 | 0.00 | 0 |
| nefird | 80.6 | 62.5 | 22.80 | 13.82 | 2.61 | 0.00 | 0 |
| drugon | 69.4 | 81.2 | 21.48 | 11.68 | 1.65 | 0.00 | 0 |
| vahign | 83.3 | 68.7 | 21.32 | 9.28 | 2.12 | 0.00 | 0 |
| lengor | 72.2 | 68.7 | 22.43 | 13.12 | 4.15 | 0.00 | 0 |
| kamign | 66.7 | 68.7 | 21.12 | 11.39 | 4.65 | 0.00 | 0 |
| materk | 75.0 | 71.9 | 21.63 | 13.98 | 6.82 | 0.00 | 0 |
| remdon | 75.0 | 84.4 | 22.24 | 12.21 | 4.43 | 0.00 | 0 |
| reatun | 77.8 | 68.7 | 22.19 | 12.45 | 6.79 | 0.00 | 0 |
| nerumb | 69.4 | 68.7 | 19.91 | 10.49 | 1.34 | 0.00 | 0 |
| esthor | 75.0 | 84.4 | 21.41 | 12.43 | 5.81 | 0.00 | 1 |
| rodipe | 72.2 | 65.6 | 21.91 | 11.44 | 2.85 | 0.00 | 0 |
| seporn | 75.0 | 65.6 | 22.65 | 14.09 | 5.39 | 0.00 | 0 |
| cepald | 50.0 | 62.5 | 22.79 | 12.58 | 2.99 | 0.00 | 0 |
| cleaps | 72.2 | 75.0 | 21 39 | 11.75 | 3.83 | 0.00 | 0 |
| notips | 77.8 | 68.7 | 22.19 | 12.56 | 5.63 | 0.00 | 0 |
| blupic | 72.2 | 81.2 | 20.35 | 10.52 | 1.98 | 0.00 | 0 |
| sidare | 75.0 | 84.4 | 22.66 | 13.05 | 3.31 | 0.00 | 0 |
| ruslet | 72.2 | 75.0 | 22.77 | 11.60 | 4.58 | 0.00 | 0 |
| shulod | 75.0 | 71.9 | 22.54 | 12.54 | 0.48 | 0.00 | 0 |
| selmip | 83.3 | 59.4 | 20.69 | 11.92 | 1.83 | 0.00 | 0 |
| takgin | 66.7 | 71.9 | 21.09 | 10.52 | 4.19 | 0.00 | 0 |
| tawdor | 80.6 | 62.5 | 21.83 | 11.44 | 0.00 | 0.00 | 0 |
| drenut | 77.8 | 81.2 | 21.24 | 11.72 | 6.82 | 0.00 | 0 |
| volmue | 83.3 | 96.9 | 21.16 | 10.92 | 4.32 | 0.00 | 0 |
| dawkel | 91.7 | 81.2 | 21.79 | 10.11 | 0.85 | 0.00 | 0 |
| dentaw | 80.6 | 78.1 | 21.53 | 12.19 | 6.47 | 0.00 | 0 |
| redkow | 58.3 | 59.4 | 20.85 | 9.14 | 1.81 | 0.00 | 0 |

Regular-Low

| ITEM | E3 | E4 | SL | BI | TRI | FREQ | I |
|---|---|---|---|---|---|---|---|
| otsalm | 72.2 | 78.1 | 20.91 | 8.97 | 0.00 | 0.00 | 1 |
| adorun | 66.7 | 65.6 | 20.34 | 6.69 | 1.86 | 0.00 | 1 |
| hebnid | 80.6 | 68.7 | 21.80 | 8.64 | 1.00 | 0.00 | 0 |
| bodnye | 61.1 | 65.6 | 21.41 | 6.67 | 1.85 | 0.00 | 0 |
| ridbeg | 80.6 | 65.6 | 21.77 | 7.89 | 1.83 | 0.00 | 0 |
| hecrag | 63.9 | 53.1 | 21.75 | 9.60 | 2.39 | 0.00 | 0 |
| nicmog | 69.4 | 68.7 | 21.38 | 6.68 | 1.20 | 0.00 | 0 |
| yotcun | 80.6 | 87.5 | 19.97 | 6.31 | 0.00 | 0.00 | 0 |
| ruscoe | 77.8 | 81.2 | 22.01 | 10.04 | 5.33 | 0.00 | 0 |
| nidseg | 61.1 | 62.5 | 21.78 | 9.23 | 0.00 | 0.00 | 0 |
| redcit | 86.1 | 81.2 | 21.49 | 9.85 | 2.29 | 0.00 | 0 |
| rigdun | 80.6 | 68.7 | 20.90 | 6.64 | 1.91 | 0.00 | 0 |
| fliyam | 72.2 | 68.7 | 19.77 | 6.50 | 1.66 | 0.00 | 0 |
| fednir | 77.8 | 81.2 | 21.99 | 9.35 | 0.00 | 0.00 | 0 |
| nodrug | 77.8 | 56.2 | 20.72 | 7.81 | 1.71 | 0.00 | 0 |
| vinhag | 77.8 | 75.0 | 21.09 | 6.87 | 0.00 | 0.00 | 0 |
| ronleg | 72.2 | 65.6 | 22.81 | 9.33 | 1.48 | 0.00 | 0 |
| minkag | 58.3 | 81.2 | 21.59 | 7.41 | 3.26 | 0.00 | 0 |
| mekart | 83.3 | 71.9 | 21.95 | 8.65 | 1.48 | 0.00 | 0 |
| nemrod | 66.7 | 90.6 | 22.47 | 10.46 | 0.00 | 0.00 | 0 |
| tearun | 66.7 | 78.1 | 21.83 | 10.46 | 3.16 | 0.00 | 0 |
| runemb | 63.9 | 53.1 | 19.60 | 8.92 | 1.08 | 0.00 | 0 |
| ershot | 83.3 | 65.6 | 21.89 | 9.15 | 1.26 | 0.00 | 1 |
| dripoe | 66.7 | 62.5 | 22.02 | 8.90 | 2.82 | 0.00 | 0 |
| resnop | 80.6 | 87.5 | 20.86 | 10.11 | 2.52 | 0.00 | 0 |
| daplec | 66.7 | 78.1 | 21.46 | 9.01 | 0.78 | 0.00 | 0 |
| celsap | 83.3 | 78.1 | 20.59 | 9.55 | 2.68 | 0.00 | 0 |
| snipot | 72.2 | 68.7 | 22.16 | 9.21 | 0.00 | 0.00 | 0 |
| clibup | 75.0 | 71.9 | 19.08 | 7.42 | 2.18 | 0.00 | 0 |
| ridasc | 72.2 | 84.4 | 21.87 | 11.37 | 3.85 | 0.00 | 0 |
| tesrul | 72.2 | 65.6 | 21.44 | 8.34 | 1.57 | 0.00 | 0 |
| lohuds | 66.7 | 65.6 | 21.66 | 8.93 | 1.63 | 0.00 | 0 |
| slepim | 83.3 | 93.7 | 20.92 | 9.81 | 1.23 | 0.00 | 0 |
| kitnag | 83.3 | 53.1 | 20.84 | 7.25 | 0.70 | 0.00 | 0 |
| darwot | 97.2 | 53.1 | 21.95 | 8.24 | 1.34 | 0.00 | 0 |
| netrud | 77.8 | 65.6 | 22.05 | 9.49 | 1.20 | 0.00 | 0 |
| vomlue | 80.6 | 93.7 | 21.31 | 9.27 | 0.00 | 0.00 | 0 |
| ledkaw | 72.2 | 62.5 | 20.61 | 5.97 | 0.85 | 0.00 | 0 |
| tewnad | 72.2 | 59.4 | 22.18 | 9.34 | 0.00 | 0.00 | 0 |
| kerwod | 83.3 | 65 6 | 21.20 | 6.58 | 0.00 | 0.00 | 0 |

## Irregular-High

| ITEM | E3 | E4 | SL | BI | TRI | FREQ | I |
|---|---|---|---|---|---|---|---|
| aslmot | 75.0 | 96.9 | 21.22 | 11.75 | 1.94 | 0.00 | 2 |
| douanr | 63.9 | 59.4 | 22.43 | 10.61 | 1.88 | 0.00 | 2 |
| bhined | 69.4 | 90.6 | 23.15 | 12.80 | 7.62 | 0.00 | 1 |
| obndey | 72.2 | 71.9 | 20.81 | 10.48 | 2.27 | 0.00 | 2 |
| ibrged | 58.3 | 84.4 | 21.53 | 11.41 | 4.63 | 0.00 | 2 |
| ghreca | 77.8 | 65.6 | 20.91 | 11.44 | 3.96 | 0.00 | 2 |
| cimngo | 58.3 | 78.1 | 20.52 | 9.51 | 0.00 | 0.00 | 2 |
| tnoucy | 72.2 | 75.0 | 22.01 | 10.71 | 3.48 | 0.00 | 1 |
| reoucs | 55.6 | 75.0 | 22.95 | 13.74 | 0.85 | 0.00 | 1 |
| igndes | 75.0 | 59.4 | 21.03 | 12.09 | 5.45 | 0.00 | 1 |
| itrced | 41.7 | 68.7 | 22.39 | 14.94 | 4.93 | 0.00 | 2 |
| urindg | 69.4 | 68.7 | 20.70 | 10.00 | 2.56 | 0.00 | 2 |
| mlfiay | 83.3 | 59.4 | 21.85 | 9.43 | 0.00 | 0.00 | 1 |
| frnied | 63.9 | 75.0 | 23.47 | 13.77 | 4.03 | 0.00 | 2 |
| ourdgn | 69.4 | 75.0 | 21.35 | 11.80 | 2.09 | 0.00 | 2 |
| vnghia | 69.4 | 62.5 | 19.35 | 9.33 | 0.00 | 0.00 | 2 |
| leorgn | 69.4 | 65.6 | 22.25 | 13.14 | 4.22 | 0.00 | 1 |
| kmaing | 66.7 | 68.7 | 20.39 | 11.39 | 5.63 | 0.00 | 1 |
| atrkem | 72.2 | 81.2 | 21.89 | 14.01 | 2.73 | 0.00 | 2 |
| enrmod | 69.4 | 65.6 | 22.18 | 12.22 | 2.08 | 0.00 | 2 |
| atrnue | 72.2 | 78.1 | 21.99 | 12.44 | 1.66 | 0.00 | 2 |
| bmuner | 77.8 | 56.2 | 21.82 | 10.48 | 2.61 | 0.00 | 1 |
| erosth | 72.2 | 59.4 | 21.39 | 12.43 | 1.78 | 0.00 | 2 |
| prdioe | 77.8 | 75.0 | 22.52 | 11.35 | 0.85 | 0.00 | 2 |
| oprnes | 77.8 | 68.7 | 22.22 | 14.13 | 4.67 | 0.00 | 2 |
| acepld | 61.1 | 56.2 | 21.99 | 12.71 | 1.59 | 0.00 | 2 |
| caepls | 77.8 | 78.1 | 22.75 | 11.72 | 2.37 | 0.00 | 2 |
| inopst | 75.0 | 56.2 | 21.23 | 12.47 | 0.00 | 0.00 | [illegible] |
| plbuic | 88.9 | 90.6 | 20.40 | 10.44 | 0.00 | 0.00 | |
| siraed | 69.4 | 71.9 | 24.01 | 13.05 | 1.78 | 0.00 | 1 |
| uertls | 88.9 | 59.4 | 23.01 | 11.51 | 2.45 | 0.00 | 2 |
| dhouls | 72.2 | 53.1 | 22.73 | 12.52 | 6.08 | 0.00 | 1 |
| spmile | 75.0 | 84.4 | 22.78 | 11.93 | 4.31 | 0.00 | 1 |
| itankg | 69.4 | 78.1 | 20.50 | 10.53 | 3.49 | 0.00 | 2 |
| otrdaw | 80.6 | 65.6 | 20.40 | 11.42 | 0.60 | 0.00 | 2 |
| untrde | 36.1 | 71.9 | 21.20 | 11.84 | 0.00 | 0.00 | 2 |
| vmouel | 55.6 | 53.1 | 21.18 | 10.91 | 3.77 | 0.00 | 2 |
| eakwld | 58.3 | 65.6 | 21.39 | 10.10 | 0.00 | 0.00 | 2 |
| deatnw | 66.7 | 71.9 | 22.05 | 9.35 | 3.79 | 0.00 | 1 |
| reokdw | 72.2 | 71.9 | 20.85 | 9.14 | 0.00 | 0.00 | 1 |

## Irregular-Low

| ITEM | E3 | E4 | SL | BI | TRI | FREQ | I |
|---|---|---|---|---|---|---|---|
| atsoml | 75.0 | 84.4 | 21.28 | 8.97 | 0.00 | 0.00 | 2 |
| onaudr | 63.9 | 62.5 | 21.24 | 6.67 | 1.20 | 0.00 | 2 |
| ohdien | 61.1 | 78.1 | 22.69 | 8.64 | 2.00 | 0.00 | 1 |
| oebndy | 61.1 | 78.1 | 20.87 | 6.69 | 0.85 | 0.00 | 2 |
| grbedi | 72.2 | 81.2 | 18.61 | 7.89 | 0.00 | 0.00 | 2 |
| hgreca | 61.1 | 65.6 | 19.71 | 9.65 | 4.07 | 0.00 | 2 |
| cgnomi | 69.4 | 56.2 | 18.32 | 6.66 | 1.28 | 0.00 | 2 |
| cntouy | 83.3 | 65.6 | 21.74 | 6.32 | 0.00 | 0.00 | 1 |
| croeus | 58.3 | 71.9 | 22.25 | 9.71 | 1.28 | 0.00 | 1 |
| gdsine | 69.4 | 78.1 | 21.40 | 9.23 | 4.37 | 0.00 | 1 |
| idrcet | 58.3 | 62.5 | 21.03 | 9.84 | 2.51 | 0.00 | 2 |
| gduinr | 72.2 | 84.4 | 20.99 | 6.63 | 0.00 | 0.00 | 2 |
| mayfli | 75.0 | 81.2 | 18.85 | 6.55 | 0.00 | 0.00 | 1 |
| ndfier | 69.4 | 56.2 | 21.47 | 9.34 | 2.31 | 0.00 | 2 |
| dnorgu | 69.4 | 59.4 | 19.58 | 7.81 | 2.11 | 0.00 | 2 |
| hngaiv | 58.3 | 46.9 | 17.22 | 6.80 | 1.15 | 0.00 | 2 |
| rnogle | 75.0 | 53.1 | 22.41 | 9.33 | 2.30 | 0.00 | 1 |
| miagnk | 72.2 | 78.1 | 20.99 | 7.43 | 0.00 | 0.00 | 1 |
| earmkt | 75.0 | 75.0 | 21.43 | 8.50 | 3.31 | 0.00 | 2 |
| orendm | 72.2 | 62.5 | 20.14 | 10.46 | 4.80 | 0.00 | 2 |
| nrauet | 66.7 | 78.1 | 22.77 | 10.47 | 0.70 | 0.00 | 2 |
| rbumen | 75.0 | 87.5 | 20.95 | 8.72 | 0.95 | 0.00 | 1 |
| hstero | 75.0 | 65.6 | 20.08 | 9.14 | 2.84 | 0.00 | 2 |
| dpireo | 75.0 | 59.4 | 20.37 | 8.84 | 4.14 | 0.00 | 2 |
| pnsero | 75.0 | 78.1 | 20.87 | 10.15 | 3.34 | 0.00 | 2 |
| caedlp | 69.4 | 65.6 | 20.79 | 9.07 | 1.95 | 0.00 | 2 |
| aclsep | 75.0 | 78.1 | 20.48 | 9.56 | 0.00 | 0.00 | 2 |
| stpino | 66.7 | 62.5 | 20.91 | 9.21 | 1.75 | 0.00 | 2 |
| oucibl | 83.9 | 84.4 | 20.43 | 7.31 | 0.70 | 0.00 | 1 |
| sierda | 33.3 | 65.6 | 20.80 | 11.45 | 1.49 | 0.00 | 1 |
| lsrtue | 63.9 | 78.1 | 21.48 | 8.34 | 3.15 | 0.00 | 2 |
| louhds | 72.2 | 43.7 | 21.67 | 8.92 | 1.63 | 0.00 | 1 |
| smplie | 80.6 | 68.7 | 21.04 | 9.80 | 2.12 | 0.00 | 1 |
| aginkt | 69.4 | 84.4 | 19.93 | 7.25 | 1.65 | 0.00 | 2 |
| orawtd | 69.4 | 68.7 | 21.14 | 8.31 | 2.35 | 0.00 | 2 |
| uerndt | 77.8 | 65.6 | 21.75 | 9.39 | 2.43 | 0.00 | 2 |
| oulmev | 69.4 | 65.6 | 18.21 | 9.30 | 2.00 | 0.00 | 2 |
| kdewla | 58.3 | 68.7 | 17.85 | 6.06 | 0.00 | 0.00 | 2 |
| deatnw | 55.6 | 56.2 | 22.05 | 9.35 | 3.79 | 0.00 | 1 |
| drkoew | 66.7 | 68.7 | 21.02 | 6.60 | 0.00 | 0.00 | 1 |

## Low Word Frequency

### Words

| ITEM | E3 | E4 | SL | BI | TRI | FREQ | I |
|---|---|---|---|---|---|---|---|
| coding | 88.9 | 78.1 | 22.56 | 15.73 | 7.61 | 0.48 | 0 |
| coined | 91.7 | 87.5 | 23.62 | 15.84 | 7.84 | 0.48 | 0 |
| confer | 97.2 | 84.4 | 22.31 | 13.13 | 4.57 | 0.48 | 0 |
| consul | 80.6 | 75.0 | 21.39 | 12.05 | 3.73 | 0.48 | 0 |
| copied | 83.3 | 78.1 | 23.50 | 14.48 | 6.99 | 0.48 | 0 |
| dearth | 97.2 | 90.6 | 21.91 | 14.67 | 8.14 | 0.48 | 0 |
| delays | 97.2 | 90.6 | 21.56 | 13.72 | 4.12 | 0.48 | 0 |
| depict | 83.9 | 90.6 | 22.20 | 13.73 | 4.70 | 0.48 | 0 |
| dispel | 91.7 | 87.5 | 22.23 | 12.14 | 5.11 | 0.48 | 0 |
| divers | 94.4 | 87.5 | 22.28 | 13.94 | 8.45 | 0.48 | 0 |
| easing | 77.8 | 71.9 | 22.75 | 15.37 | 9.99 | 0.48 | 1 |
| faiths | 80.6 | 84.4 | 22.24 | 13.61 | 6.93 | 0.48 | 0 |
| famine | 83.3 | 84.4 | 23.26 | 14.93 | 9.85 | 0.48 | 0 |
| fathom | 88.9 | 84.4 | 21.67 | 14.26 | 7.32 | 0.48 | 0 |
| forage | 77.8 | 84.4 | 22.70 | 13.70 | 7.81 | 0.48 | 0 |
| forged | 88.9 | 87.5 | 23.49 | 15.73 | 9.63 | 0.48 | 0 |
| frayed | 91.7 | 84.4 | 22.11 | 14.49 | 8.49 | 0.48 | 0 |
| gamble | 97.2 | 96.9 | 22.01 | 14.03 | 4.34 | 0.48 | 0 |
| glazes | 88.9 | 90.6 | 20.99 | 11.95 | 4.49 | 0.48 | 0 |
| golfer | 91.7 | 96.9 | 21.74 | 11.26 | 3.61 | 0.48 | 0 |
| gulped | 80.6 | 78.1 | 22.47 | 13.19 | 5.57 | 0.48 | 0 |
| hounds | 91.7 | 81.2 | 21.65 | 13.60 | 9.01 | 0.48 | 0 |
| hurdle | 77.8 | 93.7 | 22.50 | 14.27 | 7.39 | 0.48 | 0 |
| jurist | 88.9 | 84.4 | 21.72 | 14.45 | 8.08 | 0.48 | 0 |
| lather | 75.0 | 81.2 | 23.23 | 16.33 | 11.16 | 0.48 | 0 |
| magnet | 88.9 | 87.5 | 22.82 | 13.48 | 6.01 | 0.48 | 0 |
| masked | 91.7 | 96.9 | 23.18 | 14.65 | 7.78 | 0.60 | 0 |
| outcry | 86.1 | 87.5 | 21.47 | 7.34 | 1.91 | 0.48 | 1 |
| punish | 91.7 | 78.1 | 22.01 | 12.92 | 6.38 | 0.48 | 0 |
| raving | 94.4 | 81.2 | 22.39 | 15.77 | 9.44 | 0.48 | 0 |
| repaid | 83.3 | 87.5 | 22.15 | 12.95 | 7.13 | 0.48 | 0 |
| scrape | 94.4 | 90.6 | 21.88 | 12.00 | 5.33 | 0.48 | 0 |
| sinful | 91.7 | 81.2 | 20.58 | 10.21 | 5.05 | 0.48 | 0 |
| slated | 80.6 | 87.5 | 23.70 | 15.98 | 9.31 | 0.48 | 0 |
| spiced | 91.7 | 81.2 | 22.43 | 14.26 | 7.24 | 0.48 | 0 |
| sultan | 86.1 | 75.0 | 22.54 | 11.97 | 2.18 | 0.48 | 0 |
| tripod | 91.7 | 84.4 | 22.16 | 10.85 | 2.60 | 0.48 | 0 |
| tropic | 86.1 | 84.4 | 20.83 | 13.56 | 5.24 | 0.48 | 0 |
| truism | 88.9 | 81.2 | 21.19 | 10.16 | 4.64 | 0.48 | 0 |
| unlock | 86.1 | 87.5 | 19.86 | 10.14 | 4.14 | 0.48 | 1 |

## Regular-High

| ITEM | E3 | E4 | SL | BI | TRI | FREQ | I |
|---|---|---|---|---|---|---|---|
| dicgon | 69.4 | 62.5 | 21.78 | 9.92 | 1.78 | 0.00 | 0 |
| diceon | 61.1 | 84.4 | 22.26 | 11.63 | 2.03 | 0.00 | 0 |
| cefnor | 77.8 | 68.7 | 22.61 | 10.91 | 0.00 | 0.00 | 0 |
| conlus | 80.6 | 65.6 | 22.08 | 10.15 | 1.63 | 0.00 | 0 |
| diecop | 72.2 | 50.0 | 19.85 | 10.15 | 1.96 | 0.00 | 0 |
| rhetad | 72.2 | 50.0 | 22.36 | 10.82 | 1.04 | 0.00 | 0 |
| ladsey | 52.8 | 75.0 | 22.43 | 12.17 | 3.22 | 0.00 | 0 |
| dipect | 91.7 | 87.5 | 21.77 | 12.52 | 5.49 | 0.00 | 0 |
| lipsed | 75.0 | 81.2 | 22.55 | 12.59 | 3.66 | 0.00 | 0 |
| vierds | 77.8 | 78.1 | 21.16 | 12.10 | 5.21 | 0.00 | 0 |
| isagen | 75.0 | 59.4 | 21.43 | 11.92 | 4.16 | 0.00 | 1 |
| tashif | 55.6 | 50.0 | 20.99 | 10.58 | 2.96 | 0.00 | [illegible] |
| mifane | 61.1 | 78.1 | 22.55 | 11.74 | 2.30 | 0.00 | 0 |
| thamof | 69.4 | 68.7 | 20.85 | 10.40 | 2.68 | 0.00 | 0 |
| gafcor | 66.7 | 78.1 | 22.17 | 10.10 | 1.81 | 0.00 | 0 |
| foderg | 77.8 | 81.2 | 22.11 | 11.55 | 4.88 | 0.00 | 0 |
| fedary | 66.7 | 65.6 | 22.15 | 11.32 | 2.37 | 0.00 | 0 |
| begalm | 72.2 | 78.1 | 21.66 | 10.65 | 3.81 | 0.00 | 0 |
| zagsel | 66.7 | 75.0 | 19.32 | 7.66 | 1.36 | 0.00 | 0 |
| fogler | 94.4 | 84.4 | 22.69 | 12.02 | 3.11 | 0.00 | 0 |
| gudpel | 72.2 | 75.0 | 21.36 | 9.86 | 1.64 | 0.00 | 0 |
| hunods | 66.7 | 78.1 | 21.66 | 11.51 | 2.59 | 0.00 | 0 |
| hudler | 91.7 | 90.6 | 22.11 | 11.67 | 3.82 | 0.00 | 0 |
| jisurt | 72.2 | 78.1 | 21.68 | 11.50 | 3.59 | 0.00 | 0 |
| lehart | 77.8 | 59.4 | 22.12 | 12.62 | 3.01 | 0.00 | 0 |
| tamgen | 83.3 | 84.4 | 22.72 | 11.65 | 1.63 | 0.00 | 0 |
| kadems | 63.9 | 68.7 | 20.65 | 10.15 | 0.00 | 0.00 | 0 |
| otucry | 75.0 | 71.9 | 20.86 | 8.72 | 0.60 | 0.00 | 1 |
| hinsup | 72.2 | 84.4 | 19.38 | 10.56 | 2.19 | 0.00 | 0 |
| vignar | 77.8 | 59.4 | 21.21 | 11.79 | 3.80 | 0.00 | 0 |
| riedap | 72.2 | 75.0 | 20.02 | 10.35 | 0.00 | 0.00 | 0 |
| rescap | 80.6 | 71.9 | 20.18 | 11.32 | 5.76 | 0.00 | 0 |
| lufins | 72.2 | 68.7 | 22.57 | 12.27 | 3.65 | 0.00 | 0 |
| lesdat | 80.6 | 68.7 | 22.20 | 12.08 | 1.81 | 0.00 | 0 |
| pidecs | 86.1 | 90.6 | 22.30 | 12.36 | 1.83 | 0.00 | 0 |
| tanuls | 66.7 | 78.1 | 23.05 | 13.86 | 2.40 | 0.00 | 0 |
| tirpod | 72.2 | 81.2 | 22.65 | 10.72 | 0.60 | 0.00 | 0 |
| coprit | 80.6 | 78.1 | 21.85 | 11.18 | 4.68 | 0.00 | 0 |
| triums | 77.8 | 68.7 | 21.85 | 10.45 | 1.90 | 0.00 | 0 |
| uncolk | 72.2 | 75.0 | 20.20 | 10.20 | 2.51 | 0.00 | 1 |

## Regular-Low

| ITEM | E3 | E4 | SL | BI | TRI | FREQ | I |
|---|---|---|---|---|---|---|---|
| nidcog | 66.7 | 78.1 | 20.87 | 6.12 | 0.00 | 0.00 | 0 |
| nidcoe | 66.7 | 68.7 | 21.38 | 7.20 | 0.00 | 0.00 | 0 |
| cerfon | 83.3 | 68.7 | 21.89 | 9.05 | 1.23 | 0.00 | 0 |
| scolun | 56.7 | 65.6 | 21.40 | 7.66 | 1.54 | 0.00 | 0 |
| pidcoe | 66.7 | 53.1 | 21.84 | 7.86 | 0.00 | 0.00 | 0 |
| tedhar | 61.1 | 53.1 | 21.83 | 8.33 | 0.00 | 0.00 | 0 |
| saldye | 63.9 | 56.2 | 21.96 | 8.16 | 2.01 | 0.00 | 0 |
| tidpec | 66.7 | 81.2 | 21.30 | 7.47 | 0.00 | 0.00 | 0 |
| ledpis | 69.4 | 71.9 | 21.85 | 8.91 | 0.85 | 0.00 | 0 |
| sevrid | 80.6 | 90.6 | 22.58 | 10.41 | 1.59 | 0.00 | 0 |
| aginse | 66.7 | 65.6 | 20.89 | 8.16 | 0.00 | 0.00 | 1 |
| hisfat | 77.8 | 62.5 | 20.80 | 7.69 | 0.00 | 0.00 | 0 |
| neifam | 69.4 | 71.9 | 20.15 | 8.43 | 0.00 | 0.00 | 0 |
| mohaft | 66.7 | 71.9 | 20.05 | 6.22 | 0.00 | 0.00 | 0 |
| reafog | 69.4 | 75.0 | 21.41 | 7.74 | 2.76 | 0.00 | 0 |
| fedorg | 69.4 | 78.1 | 22.11 | 8.56 | 0.00 | 0.00 | 0 |
| reyfal | 72.2 | 65.6 | 20.97 | 7.95 | 0.00 | 0.00 | 0 |
| melbag | 66.7 | 90.6 | 21.67 | 7.43 | 1.53 | 0.00 | 0 |
| zeslag | 63.9 | 75.0 | 19.24 | 5.55 | 0.00 | 0.00 | 0 |
| rolfeg | 63.9 | 65.6 | 21.80 | 7.75 | 1.73 | 0.00 | 0 |
| pedlug | 66.7 | 75.0 | 21.26 | 5.88 | 0.00 | 0.00 | 0 |
| hosdun | 86.1 | 84.4 | 21.23 | 8.14 | 0.00 | 0.00 | 0 |
| helrud | 72.2 | 84.4 | 21.87 | 7.41 | 1.94 | 0.00 | 0 |
| jisrut | 72.2 | 78.1 | 20.70 | 6.04 | 0.00 | 0.00 | 0 |
| teharl | 75.0 | 65.6 | 21.72 | 9.29 | 1.53 | 0.00 | 0 |
| nemtag | 63.9 | 78.1 | 22.03 | 7.70 | 0.00 | 0.00 | 0 |
| medkas | 58.3 | 81.2 | 21.90 | 7.36 | 1.69 | 0.00 | 0 |
| otcruy | 80.6 | 75.0 | 20.60 | 5.93 | 0.00 | 0.00 | 1 |
| siphun | 61.1 | 84.4 | 21.25 | 7.68 | 0.00 | 0.00 | 0 |
| vinrag | 72.2 | 71.9 | 21.21 | 8.36 | 1.00 | 0.00 | 0 |
| reipad | 69.4 | 78.1 | 22.45 | 8.68 | 0.00 | 0.00 | 0 |
| serpac | 63.9 | 78.1 | 21.94 | 8.76 | 2.50 | 0.00 | 0 |
| lisfun | 72.2 | 56.2 | 20.41 | 8.50 | 1.98 | 0.00 | 0 |
| tedlas | 69.4 | 62.5 | 22.06 | 8.96 | 1.76 | 0.00 | 0 |
| sipdec | 72.2 | 78.1 | 21.73 | 7.49 | 0.00 | 0.00 | 0 |
| tanlus | 72.2 | 75.0 | 21.88 | 9.76 | 1.92 | 0.00 | 0 |
| ridpot | 72.2 | 78.1 | 21.66 | 9.12 | 1.83 | 0.00 | 0 |
| ritcop | 69.4 | 90.6 | 20.31 | 8.86 | 1.40 | 0.00 | 0 |
| tisrum | 61.1 | 62.5 | 20.70 | 8.51 | 1.61 | 0.00 | 0 |
| ulnock | 83.3 | 84.4 | 19.84 | 4.56 | 0.48 | 0.00 | 1 |

Irregular-High

| ITEM | E3 | E4 | SL | BI | TRI | FREQ | I |
|---|---|---|---|---|---|---|---|
| cngiod | 77.8 | 62.5 | 22.43 | 10.03 | 6.04 | 0.00 | 2 |
| cnoied | 75.0 | 75.0 | 23.66 | 11.65 | 2.20 | 0.00 | 2 |
| frneco | 72.2 | 75.0 | 20.59 | 10.91 | 1.00 | 0.00 | 2 |
| sneulo | 77.8 | 87.5 | 21.10 | 10.18 | 0.00 | 0.00 | 2 |
| eicopd | 61.1 | 75.0 | 21.76 | 10.22 | 0.00 | 0.00 | 2 |
| ehatrd | 72.2 | 65.6 | 22.76 | 10.97 | 0.00 | 0.00 | 2 |
| ylades | 63.9 | 62.5 | 21.23 | 12.20 | 5.55 | 0.00 | 1 |
| peticd | 77.8 | 56.2 | 23.49 | 12.35 | 3.36 | 0.00 | 1 |
| pldise | 75.0 | 78.1 | 22.02 | 12.46 | 2.23 | 0.00 | 1 |
| sdvier | 69.4 | 78.1 | 22.03 | 11.76 | 5.84 | 0.00 | 1 |
| aiengs | 69.4 | 62.5 | 22.23 | 11.94 | 4.01 | 0.00 | 2 |
| fhasit | 69.4 | 71.9 | 21.79 | 10.57 | 1.38 | 0.00 | 1 |
| faiemn | 63.9 | 68.7 | 22.00 | 11.70 | 4.11 | 0.00 | 2 |
| athomf | 52.8 | 65.6 | 20.05 | 10.36 | 0.90 | 0.00 | 2 |
| reoagf | 61.1 | 62.5 | 21.40 | 10.05 | 0.00 | 0.00 | 2 |
| dcorgf | 63.9 | 68.7 | 21.20 | 11.26 | 4.22 | 0.00 | 1 |
| derayf | 72.2 | 68.7 | 20.71 | 11.39 | 2.93 | 0.00 | 1 |
| eamblg | 69.4 | 65.6 | 21.78 | 10.56 | 1.94 | 0.00 | 2 |
| aglesz | 63.9 | 78.1 | 17.03 | 7.56 | 2.00 | 0.00 | 2 |
| glfoer | 80.6 | 87.5 | 22.15 | 12.11 | 0.00 | 0.00 | 1 |
| pldgeu | 72.2 | 62.5 | 20.01 | 10.00 | 2.09 | 0.00 | 2 |
| dhuson | 52.8 | 53.1 | 21.48 | 11.37 | 2.91 | 0.00 | 1 |
| uhrled | 63.9 | 65.6 | 22.68 | 11.85 | 4.58 | 0.00 | 2 |
| turisj | 83.3 | 84.4 | 18.74 | 11.68 | 7.38 | 0.00 | 2 |
| htaler | 86.1 | 81.2 | 22.50 | 12.83 | 5.04 | 0.00 | 1 |
| ntagem | 61.1 | 71.9 | 21.38 | 11.10 | 3.88 | 0.00 | 1 |
| dkasem | 47.2 | 62.5 | 19.94 | 8.42 | 1.59 | 0.00 | 1 |
| yotrcu | 55.6 | 71.9 | 18.94 | 8.71 | 0.00 | 0.00 | 2 |
| sphinu | 77.8 | 59.4 | 19.95 | 10.47 | 3.76 | 0.00 | 2 |
| grvina | 69.4 | 75.0 | 20.72 | 11.83 | 4.49 | 0.00 | 2 |
| ariedp | 50.0 | 62.5 | 20.10 | 10.28 | 3.48 | 0.00 | 2 |
| prcaes | 88.9 | 96.9 | 23.06 | 11.49 | 0.48 | 0.00 | 2 |
| fuinls | 75.0 | 68.7 | 22.58 | 12.09 | 2.89 | 0.00 | 1 |
| sa.tld | 69.4 | 65.6 | 23.60 | 12.07 | 0.00 | 0.00 | 2 |
| pscied | 58.3 | 68.7 | 22.80 | 12.40 | 2.20 | 0.00 | 1 |
| unatls | 66.7 | 81.2 | 22.20 | 13.84 | 3.75 | 0.00 | 2 |
| itoprd | 66.7 | 78.1 | 21.89 | 10.73 | 1.38 | 0.00 | 2 |
| itrcop | 75.0 | 81.2 | 19.65 | 11.16 | 0.00 | 0.00 | 2 |
| mitrsu | 66.7 | 65.6 | 20.20 | 10.37 | 0.00 | 0.00 | 2 |
| loncku | 66.7 | 59.4 | 18.98 | 10.39 | 3.10 | 0.00 | 2 |

## Irregular-Low

| ITEM | E3 | E4 | SL | BI | TRI | FREQ | I |
|---|---|---|---|---|---|---|---|
| oidcng | 52.8 | 50.0 | 20.89 | 6.08 | 0.00 | 0.00 | 2 |
| endcoi | 61.1 | 59.4 | 18.80 | 7.20 | 1.59 | 0.00 | 2 |
| efcnor | 58.3 | 56.2 | 21.33 | 9.07 | 0.00 | 0.00 | 2 |
| uslnoc | 72.2 | 68.7 | 19.85 | 7.63 | 0.00 | 0.00 | 2 |
| oedicp | 61.1 | 75.0 | 20.11 | 7.72 | 1.65 | 0.00 | 2 |
| adhtre | 58.3 | 81.2 | 21.09 | 8.24 | 0.60 | 0.00 | 2 |
| sdelay | 80.6 | 84.4 | 20.89 | 8.12 | 0.00 | 0.00 | 1 |
| tcepid | 86.1 | 75.0 | 21.36 | 7 47 | 1.38 | 0.00 | 1 |
| dpesil | 75.0 | 71.9 | 20.46 | 8.87 | 1.00 | 0.00 | 1 |
| veisrd | 69.4 | 87.5 | 22.19 | 10.40 | 0.78 | 0.00 | 1 |
| gsanei | 77.8 | 78.1 | 19.62 | 8.24 | 1.93 | 0.00 | 2 |
| sfaith | 63.9 | 65.6 | 21.73 | 7.69 | 0.95 | 0.00 | 1 |
| fniema | 66.7 | 84.4 | 20.40 | 8.26 | 0.48 | 0.00 | 2 |
| ofahtm | 50.0 | 62.5 | 19.82 | 6.23 | 0.00 | 0.00 | 2 |
| faegro | 75.0 | 68.7 | 20.62 | 7.69 | 0.00 | 0.00 | 2 |
| dgroef | 55.6 | 65.6 | 20.69 | 8.56 | 1.23 | 0.00 | 1 |
| daefry | 75.0 | 84.4 | 21.19 | 7.96 | 0.00 | 0.00 | 1 |
| maeblg | 86.1 | 68.7 | 21.90 | 7.42 | 0.90 | 0.00 | 2 |
| gszela | 61.1 | 81.2 | 18.51 | 5.50 | 1.28 | 0.00 | 2 |
| rlfoge | 55.6 | 65.6 | 21.75 | 7.74 | 0.00 | 0.00 | 1 |
| elupdg | 77.8 | 71.9 | 20.51 | 5.88 | 0.00 | 0.00 | 2 |
| huodns | 66.7 | 71.9 | 22.27 | 8.14 | 0.00 | 0.00 | 1 |
| hlderu | 44.4 | 62.5 | 19.52 | 7.39 | 3.89 | 0.00 | 2 |
| surjti | 72.2 | 71.9 | 16.89 | 6.04 | 1.96 | 0.00 | 2 |
| hletar | 83.3 | 87.5 | 21.70 | 9.32 | 1.48 | 0.00 | 1 |
| nagtme | 80.6 | 62.5 | 21.69 | 7.73 | 0.00 | 0.00 | 1 |
| deaksm | 75.0 | 50.0 | 21.16 | 9.49 | 3.17 | 0.00 | 1 |
| tcouyr | 63.9 | 53.1 | 21.04 | 5.90 | 0.00 | 0.00 | 2 |
| pshinu | 63.9 | 62.5 | 19.53 | 7.70 | 2.42 | 0.00 | 2 |
| ravngi | 63.9 | 53 1 | 19.57 | 8.38 | 0.48 | 0.00 | 2 |
| rpeida | 52.8 | 75.0 | 20.03 | 8.68 | 0.00 | 0.00 | 2 |
| earscp | 69.4 | 78.1 | 20.53 | 8.76 | 2.45 | 0.00 | 2 |
| fnilus | 72.2 | 59.4 | 21.34 | 8.50 | 0.00 | 0.00 | 1 |
| lesdta | 58.3 | 65.6 | 20.99 | 8.97 | 1.81 | 0.00 | 2 |
| sipdce | 41.7 | 56.2 | 22.12 | 7.49 | 0.00 | 0.00 | 1 |
| snltau | 61.1 | 59.4 | 20.40 | 9.84 | 0.00 | 0.00 | 2 |
| diprto | 75.0 | 81.2 | 19.81 | 9.13 | 1.86 | 0.00 | 2 |
| icrpot | 66.7 | 78.1 | 21.37 | 8.87 | 0.00 | 0.00 | 2 |
| srtumi | 80.6 | 78.1 | 20.17 | 8.43 | 1.34 | 0.00 | 2 |
| nlcoku | 63.9 | 62.5 | 18.66 | 4.59 | 0.00 | 0.00 | 2 |

## Appendix 4

The regular, very-high anagrams (R-VH) matched with respect to summed log bigram frequency, and very irregular, very-low anagrams (VI-VL). The number of orthographic irregularities is indicated beside each item.

### High Word Frequency

| R-VH | | VI-VL | |
|---|---|---|---|
| almots | 1 | amtslo | 3 |
| anourd | 1 | aoudnr | 4 |
| hebind | 0 | dnbhei | 3 |
| bondey | 0 | nbdyeo | 3 |
| briged | 0 | bdeigr | 2 |
| chager | 0 | rchgae | 3 |
| mocing | 0 | ngcmio | 3 |
| cotuny | 0 | ctnyou | 3 |
| couser | 0 | srceou | 3 |
| desing | 0 | ndgsei | 3 |
| crited | 0 | rcdtei | 3 |
| gurind | 0 | dgnriu | 4 |
| fimaly | 0 | lmyifa | 3 |
| frined | 0 | rfdnei | 3 |
| durong | 0 | ngrduo | 4 |
| navigh | 0 | gvnaih | 3 |
| loreng | 0 | rglnoe | 3 |
| tarkem | 0 | mtrkae | 3 |
| morned | 0 | nrmdoe | 3 |
| kaming | 0 | gmnkia | 3 |
| tauner | 0 | nraetu | 3 |
| burmen | 0 | rbmneu | 4 |
| otsher | 1 | ohsetr | 3 |
| poried | 0 | pdreio | 3 |
| pornes | 0 | nrpsoe | 3 |
| calped | 0 | dlaecp | 3 |
| calpes | 0 | pcaesl | 3 |
| posint | 0 | nstpoi | 3 |
| cublip | 0 | bpiucl | 3 |
| saried | 0 | sraedi | 3 |
| surtle | 0 | tseulr | 3 |
| hosuld | 0 | dlsuoh | 4 |
| limpes | 0 | mlpsei | 3 |
| kating | 0 | ktngai | 3 |
| watcrd | 0 | dtaowr | 3 |
| nurted | 0 | tduenr | 3 |
| vomule | 0 | muoevl | 4 |
| wakeld | 0 | lkdwea | 3 |
| watend | 0 | wtaedn | 3 |
| wroked | 0 | krwdoe | 3 |

## Low Word Frequency

| R-VH | | VI-VL | |
|---|---|---|---|
| docing | 0 | cgdnio | 3 |
| conied | 0 | dcoeni | 3 |
| focren | 0 | fnoecr | 3 |
| nucols | 0 | nclsou | 3 |
| poiced | 0 | dpoeci | 3 |
| hardet | 0 | hrdtae | 3 |
| saldey | 0 | syaedl | 3 |
| citped | 0 | tcpdei | 3 |
| sidple | 0 | ldpsei | 3 |
| visder | 0 | rsiedv | 3 |
| aniges | 1 | isgnae | 3 |
| fasith | 0 | fthsai | 3 |
| famien | 0 | fnmaei | 4 |
| fomath | 0 | taomfh | 3 |
| foager | 0 | gfaoer | 4 |
| geford | 0 | drgfoe | 2 |
| fardey | 0 | frdyae | 3 |
| gembal | 0 | lmbgea | 3 |
| galzes | 0 | zslgae | 3 |
| leforg | 0 | rfldoe | 3 |
| peguld | 0 | dleupg | 3 |
| shudon | 0 | sdhnou | 3 |
| hureld | 0 | ldhreu | 3 |
| jurits | 0 | tjrsiu | 4 |
| thaler | 0 | lhaetr | 3 |
| gemant | 0 | tmngae | 3 |
| smaked | 0 | sdmkea | 3 |
| ocutry | 1 | uoytcr | 3 |
| hupins | 0 | hpiusn | 3 |
| varing | 0 | rngvia | 4 |
| peraid | 0 | rdpaei | 4 |
| ceraps | 0 | sraepc | 3 |
| nifuls | 0 | lniufs | 3 |
| dastle | 0 | dtaesl | 3 |
| piceds | 0 | pdcsei | 3 |
| slanut | 0 | ltnsau | 3 |
| pidrot | 0 | tdrpio | 3 |
| pocirt | 0 | rcptio | 3 |
| tumsir | 0 | tmrsiu | 3 |
| uncolk | 1 | ukcnlo | 4 |

## Appendix 5

### Regularity Instructions for Paired-Judgments

Thank you for participating in our research.

Our research is directed at discovering what it is about English words that allows us to look at strings of letters and judge how much they resemble words. In trying to understand the structure present in words, we have focused on an important component property--regularity of letter sequencing. For example, there are many consonant sequences which can begin words (e.g., wh, fr, dr, and fl) but can not end words. Similarly, some regular consonant sequences at the end of words (ng, ld, ct, and ls) can not begin words. There are regular vowel sequences (e.g., ea, and ou) and irregular sequences (e.g., aa and ae). Finally, there is regularity in how these consonants and vowel groupings are themselves sequenced within words.

You will be shown pairs of six-letter strings which have been constructed to vary along this dimension of letter sequence regularity. That is, some strings preserve normal letter sequencing while others violate normal sequencing to a lesser or greater degree. Some of the strings will be words, but most will be meaningless. Whether a string is a word is not directly relevant.

The object of this experiment is to determine how well you can judge the regularity of letter sequencing in the six-letter strings. You are to evaluate both members of each pair and choose the more "regular" of the two, e.g., the string that is the most regular in terms of letter sequencing. Make your choice by hitting the button on the same side as the more "regular" member of the pair.

The first 10 pairs should give you a feel for the task. Try to work reasonably quickly and at a fairly steady pace. You must make a choice for each pair, guessing if necessary.

The experiment is divided into two sessions, with a 5 minute break between them. The entire experiment should take a little over an hour. At the beginning of each session, you will see "START" on the screen. When this happens, be sure to press the "start bar" on the keyboard in front of you. When performing the tasks, you should sit comfortably with your two index fingers resting lightly on the two response buttons not covered by cardboard. Be sure not to apply pressure on the cardboard cover on the keyboard, as this can cause the keys to be accidently depressed.

## Appendix 6

### Frequency Instructions for Paired-Judgments

Thank you for participating in our research.

Our research is directed at discovering what it is about English words that allow us to look at strings of letters and judge how much they resemble words. In trying to understand the structure present in words, we have focused on an important component property--the frequency of letter groups occurring at specific positions. Groups of letters occur with varying frequency at different positions within words. For example, you can probably think of words that end in ed and words that end in ls, but ed is about ten times more frequent than ls in final position. Likewise, st and dy both occur at the beginning of words, but st is over 100 times as frequent in initial position. In the middle of words, the vowel group ai is almost 10 times as frequent as the vowel group ao.

You will be shown pairs of six-letter strings which have been constructed to vary along the dimension of letter group frequency by position. That is, some strings have been created with letter groups that are very frequent in those positions in English words while other strings have letter groups that are very infrequent in those positions. Some of the strings will be words, but most will be meaningless. Whether a string is a word is not directly relevant.

The object of this experiment is to determine how well you can judge the frequency of letter groups in the six-letter strings. You are to evaluate both menbers of each pair and choose the more "frequent" of the two, e.g., the string that has the most frequent letter groups at the appropriate positions. Make your choice by hitting the button on the same side as the more "frequent" member of the pair.

The first 10 pairs should give you a feel for the task. Try to work reasonably quickly at a fairly steady pace. You must make a choice for each pair, guessing if necessary.

The experiment is divided into two sessions, with a 5 minute break between them. The entire experiment should take a little over an hour. At the beginning of each session, you will see "START" on the screen. When this happens, be sure to press the "start bar" on the keyboard in front of you. When performing the tasks, you should sit comfortably with your two index fingers resting lightly on the two response buttons not covered by cardboard. Be sure not to apply pressure on the cardboard cover on the keyboard, as this can cause the keys to be accidently depressed.

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