ENCODING IN WORD PERCEPTION:

AN EXPLANATION OF THE WORD SUPERIORITY EFFECT

by

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ABSTRACT

The finding that words are perceived better than unrelated letter strings of equal length has been attributed to many causes, among them the use of additional whole-word features and sophisticated guessing aided by the redundancy inherent in an alphabetic writing system. One group of models currently being put forth to explain the "word superiority effect" are the encoding models. According to such models, although the letters of an unrelated letter string may be initially perceived as accurately as the letters of a word, words enjoy the advantage of superior encoding into a form which can then be retrieved.

One prediction of these encoding models is that interference with the initial identification of the letters should serve to weaken the word superiority effect, if the successful encoding of a word is dependent upon the identification of all of the letters. If all the letters are not identified, the higher-order units of encoding will not be
activated and the encoding advantage will be lost. Even if the identification of a majority (but not all) of the letters is sufficient to fire a higher-order unit detector with which the letters are compatible, interference with letter identification should reduce the word advantage. With fewer letters identified, the probability of triggering the correct higher-order unit detector is reduced; consequently, the advantage gained by higher-order unit encoding is reduced. The other models of the word superiority effect, additional features models and redundancy models, do not make this prediction.

The first series of experiments employed various means of interfering with the ease of initial processing of the letters. These included: 1) the use of upside down instead of right side up stimuli (Experiment 1); 2) the use of script (cursive) writing instead of print writing (Experiment 2); 3) the use of an anonymous person's handwriting instead of standard press-on lettering (Experiment 2); 4) the use of stimuli presented under conditions of poor rather than good contrast (Experiment 3). In all conditions, exposure durations were adjusted so that a 50% accuracy level (averaged over stimulus types) was maintained. Each of these manipulations significantly reduced the relative advantage of words over letter strings, thus supporting the encoding models of word recognition.

In an effort to distinguish between encoding models which consider the word to be the unit of encoding and encoding models which consider smaller units such as spelling patterns to be the units of encoding, serial position curves were plotted. These curves were flat for word stimuli, supporting the whole-word encoding view. Curves for unrelated
letter strings were U-shaped, suggesting an ends-first encoding of the individual letters. To control for the possibility that the pattern of shapes of these curves was an artifact of accuracy level, in Experiment 4 the accuracy of each stimulus type was set at about 50%. The same pattern of curve shapes emerged.

Further analysis of the data revealed that words were usually reported either entirely correctly or entirely incorrectly, while nonwords were more often reported partially correctly. Thus it appears that words are encoded as whole units and not as groups of units based upon spelling patterns.

Experiment 5 demonstrated that the whole-unit encoding strategy is one which varies with the expectancies of the perceiver.
# Table of Contents

I) Abstract .................................................................................................................. 2
II) Table of Contents .................................................................................................... 5
III) Biographical Note .................................................................................................. 8
IV) Acknowledgements ................................................................................................. 9
V) Introduction ............................................................................................................. 10
   A) Larger-Unit Feature Models .................................................................................. 11
   B) Response Bias ....................................................................................................... 12
   C) Redundancy Models .............................................................................................. 13
      1. whole-word redundancy .................................................................................... 13
      2. sophisticated guessing ...................................................................................... 14
      3. feature-selection ............................................................................................... 16
   D) Encoding Models .................................................................................................. 17
      1. spelling patterns ................................................................................................. 19
      2. vocalic-center groups ....................................................................................... 21
      3. whole-word detectors ....................................................................................... 22
   E) The Present Investigation ...................................................................................... 23
VI) Evidence for the Encoding Models ......................................................................... 29
   A) Experiment 1 ....................................................................................................... 29
      1. Introduction ....................................................................................................... 29
      2. Method .............................................................................................................. 29
      3. Results .............................................................................................................. 33
      4. Discussion ....................................................................................................... 34
B) Experiment 2 ........................................ 38
   1. Introduction .................................. 38
   2. Method ....................................... 41
   3. Results ..................................... 46
   4. Discussion .................................. 48

C) Experiment 3 ..................................... 56
   1. Introduction ................................ 56
   2. Method ..................................... 56
   3. Results ..................................... 58

D) General Discussion ............................. 59

VII) Distinguishing Among the Encoding Models .......... 63
   A) Serial Position Curves ..................... 65
      1. Experiment 1 .............................. 65
      2. Experiment 2 .............................. 68
      3. Experiment 3 .............................. 72
   B) Discussion .................................. 73
   C) Experiment 4 ................................ 85
      1. Method ................................... 85
      2. Results .................................. 87
      3. Discussion ................................ 91

VIII) The Effects of Expectation on Encoding - Experiment 5 .. 94
   A) Introduction ................................ 94
   B) Method ..................................... 94
   C) Results .................................... 96
   D) Discussion .................................. 99
Biographical Note

The author grew up in the Long Island town of Bethpage, near Hicksville, a town whose name alone provides the best description of the entire region. Her first exposure to psychology occurred when, as an adolescent, she observed Patty Duke's use of the "reverse" form thereof to thwart a maternally imposed punishment. A more conventional exposure to the field was initiated by Psych 1A/1B at the University of Pennsylvania by the end of which the author was committed to psychology (i.e. had been declared a psych major). Three courses in social psychology were sufficient to dissuade the author from further work in that area. As a work-study student she entered the employ of a Penn graduate student doing research in cognitive psychology. The work was hard, the pay was poor, and in accordance with the dictates of cognitive dissonance she chose the field for her own. The author graduated in 1973 from the University of Pennsylvania and entered the M.I.T. Department of Psychology in September of 1974. The author lives in Cambridge, hates winter, and owns a heated waterbed.
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This is a Rhonda B. Friedman Thesis, starring Rhonda B. Friedman
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Filmed on location
The following is based on a true story

RBF Productions MCMLXXVIII
When the reader of an alphabetic writing system recognizes a word, what has occurred? Has he identified each of the individual letters which make up the word, one by one, in left-to-right order? Or has he identified all the letters in parallel? Has he Indeed identified any of the letters at all?

The great advantage of an alphabetic language over an ideographic one is that the young reader need only learn a small number of visual symbols which map onto the speech sounds which he already knows. By transforming visual patterns into sounds, the child can "hear" and thus recognize words which he has never seen in print before. Such phonemic translation requires identification of each letter in left-to-right fashion.

Up until the late 1800's there was little reason to doubt that skilled readers, too, scanned the letters of a word in left-to-right fashion. But in 1878, Javal (as cited in Woodworth, 1938) watched readers' eyes and observed that the seemingly smooth motion of the eyes across a page of text really consists of a series of discrete jumps, or saccades. Erdmann & Dodge (1898, as cited in Woodworth, 1938) confirmed this observation, and showed that it is only while the eyes are stationary, in between saccades, that reading itself occurs. This raised doubts about the seriality of letter-scanning. In addition, Cattell (1885) reported that more letters could be correctly reported from a briefly-flashed string of letters if the letters made up a word than if they did not make up a word. And, Erdmann & Dodge (1898) discovered that words could be correctly identified at a distance at which individual letters could not be identified. All of these
observations, taken together, led to the conclusion that letters could not possibly mediate word recognition.

Cattell's (1885) discovery that letters in words are perceived better than unrelated letters marked the beginning of a long history of studies and explanations of the 'word superiority effect' (see Krueger, 1975, for a review). Investigators saw the word superiority effect as a potential key to the understanding of how words are read. If something about the way in which words are processed enables the reader to perceive them better than nonwords, then by studying the conditions under which such a word advantage occurs one should discover some important principles about how we read.

**Larger-Unit Feature Models**

The abandonment of a model of word recognition mediated by letter recognition led to the belief that words are perceived as whole units. Pillsbury (1897), upon discovering that subjects often reported having seen the word FOREVER when presented with FOYEVER, concluded that the shape of a word is crucial in its identification. More recently, Havens & Foote (1963, 1964; Foote & Havens, 1965) provided experimental evidence that word shape is used in word recognition. Other whole-word cues that were suggested included internal shape, i.e. smaller patterns within the word, such as vertical strokes and curves (Messner, 1903, as cited in Woodworth, 1938) and dominant letters, as those with ascenders or descenders (Zeitler, 1900, as cited in Woodworth, 1938). Wheeler (1970) has put forth the possibility that spelling pattern shapes may play a role in word recognition. For example, a reader may learn to recognize the overall shape of the bigram th,
which might often occur in a word, while \texttt{ht}, which would rarely occur in a word, may be less readily recognized.

These whole-word and spelling-pattern feature accounts of word recognition soon ran into difficulty. Cattell's finding that word perception is superior to the perception of unrelated letter strings is easily replicated using upper-case stimuli (Manelis, 1974; McClelland, 1976; Reicher, 1969; Spoehr & Smith, 1975) for which overall word-shape and dominant letters would not be valuable cues. Furthermore, words can be recognized in any number of different type fonts, and indeed Cattell's word superiority effect can be obtained in a large number of different fonts. A theory which accounts for the superior perception of words by appealing to whole-word features must postulate the existence of an extremely large number of whole-word templates in long-term memory in order to take into account the wide variety of type fonts for which the effect holds. As this seemed improbable to many psychologists, other means of accounting for the word superiority effect became popular.

\textbf{Response Bias}

One solution to the problem was to claim that the effect occurred at the level of response, not at the level of perception. The response bias model states that words are simply more likely to be guessed correctly than nonwords, even when the subject has seen nothing (Goldiamond & Hawkins, 1958). The obvious problem with this explanation is that the probability of correctly guessing a word, while perhaps greater than the probability of correctly guessing a nonword, must be far too small to have any noticeable effect, given the large number of words the sum of whose probabilities must
equal one. Therefore, this model will not be discussed further.

Redundancy Models

A large class of models were recently proposed which postulate that the word advantage over letter strings is a result of the redundancy of words. That is, knowledge of permissible letter sequences may combine with partial perceptual information to limit the possibilities of the word presented. Thus, less perceptual information is required for words than for nonwords.

Redundancy models may be divided into two classes: whole-word redundancy models (F. Smith, 1971) and sophisticated guessing or "fragment" models (Newbigging, 1961; Wheeler, 1970). The whole-word redundancy model has been described in detail by F. Smith (1971). It is like the whole-word unit models of the earlier investigators in that it claims that word recognition is not mediated by individual letter recognition. Smith justifies this claim with the same evidence invoked by Cattell (1885) and Pillsbury (1897). However, his model is unlike theirs in that it does not appeal to the notion of additional features such as word shape. Instead, this feature redundancy model asserts that words are recognized directly from the features of letters. The word advantage occurs because only some of the features of each letter need be identified in order to uniquely specify a word. For example, while these features, \( \_ \), may occur in several letters (e.g., B, D, P, etc.), and the feature, \( \_ \), likewise may occur in several letters (e.g., K, M, X, etc.), the features, \( \_ \), in position one and, \( \_ \), in position two of a two-letter word (\( \_ \_ \)), can only occur in the word \( BY \). The reader would have required additional featural information in order to correctly identify either letter had it been presented singly.
A problem for this theory was presented when Miller, Bruner, & Postman (1952) demonstrated that the word superiority effect may be obtained with pseudowords, nonwords which follow the orthographic rules of the language. They found that the word superiority effect increases as a letter string's order-of-approximation to real English words increases. These results could not be explained by appealing to whole-word redundancy.

Evidence against whole-word features and in support of word identification mediated by letter identification was provided by a study involving mixed-case stimuli (McClelland, 1976). In that study a large word superiority effect was obtained even when the stimuli were composed of a mixture of upper and lower case letters. This result cannot be attributed to the use of whole-word feature sets, since it is implausible to assume that the features of mixed-case words are stored in long-term memory.

A redundancy model which allows for the initial identification of letters is the sophisticated guessing model (Newbigging, 1961; Rumelhart & Siple, 1974). According to this model, the word advantage is said to emerge in situations in which some letters of a word are identified while others are not, or where each letter of a word may be narrowed to a small subset of possible identities. In such situations, knowledge of the constraints of orthography may combine with featural information, enabling the reader to generate a "sophisticated" guess of the identities of the unknown letters. In the first case, in which some letters have been identified, the identified letters may limit the identities of unknown letters. For example, if a reader has identified the last three letters of a four-letter word to be NOB, then s/he knows that the first letter must be S or K. If, addition-
ally, the reader has detected the presence of a curve in position 1, the first letter is further limited—it must be S. In the second situation in which sophisticated guessing may play a role, the possible identities of each letter may jointly limit the identities of each other. For example, if the alternatives were narrowed down to $\frac{F}{E} \frac{E}{C} \frac{C}{N} \frac{E}{A} \frac{A}{O} \frac{H}{E}$, the only possible word would be EACH.

By allowing for letter identification as a prerequisite to word recognition, sophisticated guessing models do not suffer from the problem of overload in long-term memory—each word is stored only once, as a description or ordered list of the letters of which it is composed. The individual letters must still be represented in many forms in memory; however, it is much more reasonable to postulate many representations of 26 letters than many representations of thousands of words. Another advantage of these models is that they can account for the orthographic effect. If the second letter of an orthographically-regular word or pseudo-word is identified as R, and the first letter has been narrowed down to S or C, orthographic constraints dictate that the first letter must be C regardless of the identities of the rest of the letters, since SR in the beginning of a letter string violates the rules of orthography.

In 1969 an experiment by Reicher caused some apparent trouble for the sophisticated guessing models. Reicher attempted to eliminate any advantage of redundancy by providing a forced-choice alternative for both words and nonwords immediately after stimulus presentation. For example, if WORD were the stimulus, the subject might have to choose from the alternatives $\_\_\_D$ or $\_\_\_K$. Likewise, if the stimulus were PSLD the subject might have to
choose between _ _ _ D and _ _ _ K. Any advantage obtained for words could not be attributed to post-perceptual guessing, sophisticated or not, since both D and K complete a word in the first instance and a nonword in the second instance.

Thompson & Massaro (1973) do not agree that Reicher's paradigm controls for redundancy. They reasoned that if the subject holds off on his decision as to the letters' identities until the alternatives are presented, then they should have more trouble with physically similar alternatives than with dissimilar ones. They carried out an experiment to test this prediction and found the expected word advantage, but no difference between trials in which the alternatives were similar and those in which they were dissimilar. They concluded that letter identities are determined prior to presentation of the alternatives and therefore any effects of redundancy would occur before the alternatives were presented.

Based upon the supposition that context (redundancy) has its effect early in the perception process, a "feature-selection" or "discrimination net" model has been proposed to account for the word superiority effect (Wheeler, 1970; Manelis, 1974). This model postulates that the initial extraction of certain features leads to the tentative identification of letters and possible words, which directs the subsequent featural tests that are made. Thus, this model places the locus of effect of redundancy at the feature extraction stage, earlier in the perceptual process than the sophisticated guessing or whole-word feature-set models. As an example of how this would occur, suppose that an initial analysis of visual features reveals that the first three letters of a four-letter word are KNO and that
the fourth letter contains a vertical line. A search through lexical memory indicates that T and B are the only letters with a vertical line which would complete a real word if they occurred in the fourth position. The next step, then, might be to search for a curve of any sort. If found, the word is KNOB; if not, the word is KNOT. Carrying out such a procedure with a nonword would distinguish between letters with curves and letters without curves but would still leave many possibilities for the fourth letter.

In another attempt to discredit both the sophisticated guessing and feature-selection models, Johnston (1978) systematically varied the degree of redundancy in his stimuli. For example, _NOB is highly redundant because only two letters in the first position would complete a word. But _AIL is low in redundancy, since many letters could complete a word in the first position. If subjects are making use of redundancy, as they are according to these models, then highly redundant words should have an advantage over less redundant words. No such difference was found.

While failure to find support for a group of models does not prove that these models are incorrect, these results certainly do provide trouble for the redundancy models. Results such as these have led investigators to look elsewhere for the cause of the word superiority effect.

The Encoding Models

One observation noted by many of the early investigators (Cattell, 1885; Erdmann & Dodge, 1898; Pillsbury, 1897) was that subjects often reported that they did see a clear picture of all the letters at the time of presentation, even when they could not correctly report all of the letters. This
led Schumann (1921–22, as cited in Woodworth, 1938) to believe that when a word is presented briefly, the subject perceives the whole word clearly for an instant, thereby receiving an adequate supply of cues for recognition of the word. Woodworth (1938) goes along with this conclusion, stating that the primary cue to word recognition is "...the clear view of letters and familiar letter groups, obtained for an instant during the direct fixation of a word" (p.744).

The explanation of the word superiority effect which follows from this conclusion—that all letters are seen in both words and nonwords but words can be encoded more efficiently—had not received further consideration for many decades. Neisser (1967) discussed it briefly, then dismissed it on the grounds that the word superiority effect holds even for stimuli as short as four letters in length, surely not exceeding the span of memory.

In recent years the encoding explanations of the word superiority effect have re-emerged. According to current encoding models, short-term memory is not the limiting factor here. Rather, the problem occurs before the stimulus has entered short-term memory. Encoding models distinguish between early stages of perception, i.e. the processing of stimulus information into a form which can then be used at a later stage of processing, and later encoding stages, in which output from any level of perceptual processing is transformed into a form which is accessible for retrieval (Estes, 1975). It is at this encoding stage that words gain an advantage over nonwords.

The encoding models, which will be the central focus of the present investigation, come in several different forms, each postulating a different
higher-level unit of encoding. For Gibson et. al. (1962) the spelling pattern is the unit which is coded in reading. Smith & Spoehr (1975) claim that the stimuli are recoded into speech, the recoding being done on syllable-like units called "vocalic center groups". According to McClelland and Johnston (1977), the entire word is recoded as a single unit.

Gibson's position is that reading is the decoding of graphic units into the phonemic patterns of spoken language (Gibson et. al., 1962). However, the letters of the alphabet are not the proper unit, since they do not have an invariant mapping onto sound. The unit proposed by Gibson is the spelling pattern, defined as "a cluster of graphemes in a given environment which has an invariant pronunciation according to the rules of English" (Gibson, 1965, p. 1071). The cluster may be several letters or a single letter. The rules for grapheme-phoneme correspondence depend upon preceding and/or following letters. As an example, the letter C occurring in the middle of a word followed by an I and another vowel has an invariant pronunciation—it is always pronounced /s/ (e.g., social, ancient).

In a more recent paper (Gibson, 1970) Gibson modified her view somewhat. In the new version, the reader need not map spelling patterns into sound himself/herself. Rather, the reader may simply make use of the orthographic rules concerning spelling patterns which were determined by an invariant mapping to speech.

The reason that words are better perceived than nonwords, according to this view, is that words are composed of such spelling patterns, while non-
words are less likely to be so constructed. Such a model predicts that nonwords which are deliberately constructed to have a high spelling-to-sound correlation, according to the rules of pronunciation, should be more easily perceived than nonwords with low spelling-to-sound correlation. Gibson et. al. (1962) carried out an experiment to test this prediction. An example of a high correlation nonword which they used is GRISP. GR has an invariant pronunciation in the initial position of a word, SP has an invariant pronunciation at the end of a word, and I has an invariant pronunciation when preceded by GR and followed by SP. A low correlation nonword was formed from each high correlation nonword by reversing the initial and final consonant clusters. The results of the experiment confirmed the prediction: nonwords with high spelling-to-sound correlation were perceived significantly better than nonwords with low spelling-to-sound correlations.

Gibson is somewhat vague about what she means by the "unit" of written language. At times her position sounds similar to the letter-pattern shape model suggested by Wheeler (see p. 110 of this thesis), as in the paper by Gibson et. al. (1962): "...while reading is based on the discrimination and identification of visual forms such as letters, it becomes, in the skilled reader, a process of perceiving 'super-forms' ..." (p. 564). Overall, however, it does appear that the spelling pattern unit is intended as a unit of encoding. The other encoding models, to be discussed below, are more specific about the role of higher-order units in encoding and their role in the word superiority effect.
The model proposed by Spoehr & Smith (1973) originally postulated that the unit of perceptual encoding is the syllable. Experimental results led them to modify their position, so that a syllable-like unit, called the "vocalic center group" replaced the syllable as the encoding unit. A vocalic center group is "a letter sequence that contains one vocalic element, a single vowel or a diphthong, and from zero to three consonants or semi-consonantal elements preceding or following the vocalic element" (Smith & Spoehr, 1974, p. 260). According to the model, letter features are extracted, the letters are identified, and then the letters are parsed in vocalic center groups so that translation to an acoustic code may occur. A word or nonword consisting of a single vocalic center group can thus be translated as a single unit while a letter string which does not comprise such a unit may have to be encoded on a letter-by-letter basis.

In a later paper (Spoehr & Smith, 1975), the vocalic center group model is elaborated to account for the finding that letter strings which contain spelling patterns but no vocalic center group (e.g., BLST) are better perceived than letter strings which do not contain spelling patterns (e.g., LSTB). In this new version of the model, the initial parsing process still accounts for some of the difference between pronounceable and non-pronounceable words. But, in addition, the amount or depth of processing required to recode each vocalic center group into a phonological code contributes to the effect. The amount of processing is said to increase as the number of violations of rules of pronunciation increases. Since spelling patterns do not contain any internal violations of such rules, items composed of spelling patterns (BLST) may only violate
these rules between spelling patterns. Items composed of fewer spelling patterns contain more violations and hence take longer to recode.

This model accounts for the effects of orthographic regularity and pronounceability previously mentioned. However, one problem with this model, as noted by its authors (Smith & Spoehr, 1974), is that it assumes that phonological recoding must occur during word recognition. This assumption may not always be true, and indeed, it has been argued that such recoding does not usually occur during the course of normal reading (F. Smith, 1971; Kolers, 1970). Others claim that phonological recoding does occur during silent reading (see Bradshaw, 1975, for a discussion). Some evidence against phonological recoding was provided by Baron & Thurston (1973) who found no difference in tachistoscopic recognition accuracy between homophonic word pairs (FORE-FOUR) and nonhomophonic pairs (SORE-SOUR). And, Gibson et. al. (1970) have shown that deaf subjects perceive items composed of spelling patterns better than random letter strings, even though it is not very likely that they are recoding the letters into an acoustic code.

A model of word perception which does not claim that words are translated into a phonological code has been proposed by McClelland & Johnston (1977). Their model is a hierarchical one in which the output from feature detectors feed into letter detectors which, in turn, feed into word detectors. A detector may be thought of as a unit in long-term memory which may become activated when it receives sufficient evidence that it matches the physical stimulus being processed. Activation of any of these detectors does not necessarily mean that the correct response
can be made; it is assumed that activation must be sustained for a certain amount of time before the output is translated into a response. The cause of the word superiority effect is the differential effect which patterned masking has upon the word detectors and the letter detectors. The mask, containing features of letters, will disrupt activation at the letter level. Word detectors, one step removed, will be less susceptible to the effects of the mask and can thus continue their activity until successful translation has occurred.

This account of the word superiority effect, while eliminating the need for an acoustic coding of word stimuli, does not explain why pronounceable nonwords are perceived better than non-pronounceable ones. To account for the pseudoword advantage over unrelated letter strings, McClelland & Johnston (1977) suggest that while pseudowords, too, are represented in an abstract form which is less susceptible to disruption from masking, this representation must be constructed on the basis of the output from the letter detectors. The suggested representations which are constructed are sequences of abstract phonological codes. Thus, for pseudowords, this model is similar to that of Spoehr & Smith (1975). However, McClelland & Johnston (1977) do not commit themselves to this particular form of code. Other abstract codes may be postulated which are compatible with their model.

The Present Investigation

The present investigation has three aims: 1) to provide support for a model that locates the word superiority effect at an encoding stage after letter identification, 2) to obtain evidence which distinguishes among encoding models—those which postulate the whole word as a unit of encoding
and those which postulate a unit greater than a single letter but smaller than a word as the encoding unit, and 3) to gather evidence which bears on the issues of a) how pseudowords are encoded, and b) automaticity in the encoding of large units.

The Generic Encoding Model

The first part of this study is designed to distinguish between the generic encoding model, depicted in Figure 1, and the other models described. The encoding model is a hierarchical one in which feature detectors are activated by the sensory information from the physical stimulus, letter detectors are activated by the output from the feature detectors, and higher-order unit detectors are activated by the output from the letter detectors.¹

Insert Figure 1 about here

The output of both letter detectors and higher-order unit detectors may be encoded. However, activation of a detector does not necessarily mean that encoding has occurred; it simply means that the output of the detector can be used in further processing. Encoding is dependent upon the detector remaining activated for a certain amount of time.

When an unrelated letter string is presented, the output from the letter detectors which are activated does not activate any higher-order unit detectors. Hence unrelated letter strings can only be encoded as a series of individual letters. When words or pseudowords are presented, higher-order unit detectors may be activated. Therefore, words and pseudowords may be encoded as fewer (higher-order) units. The advantage of orthographically-regular letter strings over unrelated letter strings, then, comes from the possibility of encoding fewer units, resulting in more efficient encoding.
Figure 1: The generic encoding model.
Under normal circumstances, when a letter string is presented clearly, letter identification occurs in parallel and is automatic. Thus in a clear stimulus letters are identified relatively quickly, with very little variance in the time needed to identify the letters. However, when the stimulus is not clear, letter identification is slowed down and there is likely to be an increase in the variability of letter identification. As a result, there is a greater probability that, on a given trial, some of the letters will be identified while others are not identified.

If all of the letters are not identified, then encoding efficiency of words will be reduced for either of two reasons: 1) The identification of all of the letters may be necessary before activation of higher-level units can occur. As a consequence, encoding of the letter string will necessarily proceed in a letter-by-letter fashion if all of the letters are not identified. Hence, any advantage which words and pseudowords would have had by virtue of higher-order unit encoding will be destroyed. 2) The identification of most but not all letters may be sufficient to fire a word detector which is compatible with the letters identified. Thus identification of the letters RO_E might be sufficient to activate the detector for ROPE or for ROSE or for ROLE, thereby insuring successful encoding of the three letters which were identified. However, the use of the higher-order units in this situation does not provide as large an advantage as it would if all letters were identified since in this situation three are being encoded as one whereas four are encoded as one if all four letters are identified. In either case, the encoding model predicts that interference with the initial identification of letters (in a way likely to increase variability)
should cause a reduction in the word superiority effect.

The first three experiments were designed to test this prediction. Four different means of interfering with initial letter identification were employed in the three experiments. In each experiment, perception of words, pseudowords, and unrelated letter strings, presented under conditions assumed to slow down letter identification, were compared with perception of these stimuli presented under conditions deemed favorable to the identification of the letters. It was expected that the word superiority effect obtained in the former condition would be smaller than the word superiority effect obtained in the latter condition.

The manipulations employed in these experiments will serve to increase the difficulty of letter identification per unit time, thereby increasing the variability of letter detection. In order to maintain a relatively constant overall accuracy level across conditions, it will be necessary to increase the exposure duration of the stimuli presented under poor visual conditions in order to bring the accuracy level of these stimuli up to a level compatible with that obtained when the stimuli are clearly presented.
EVIDENCE FOR THE ENCODING MODELS

EXPERIMENT 1

The first experiment compares the relative accuracies on words, pseudowords, and unrelated letter strings presented in a normal upright fashion with the relative accuracies of the three stimulus types presented upside-down. Turning the stimuli upside-down should cause greater difficulty in identifying the individual letters, since letters are not commonly read in this orientation. Since, according to the encoding model, the word advantage occurs at a stage which follows, and is dependent upon, correct identification of all or most of the letters, interference with letter identification in this manner should serve to reduce the encoding advantage.

Method

Stimuli and Apparatus

The stimuli were 4-letter strings, either words, pseudowords, or unrelated letter strings. The pseudowords were judged to be pronounceable according to the spelling-to-sound correspondence rules of English, and to have acceptable spelling patterns. The unrelated letter strings did not have acceptable spelling patterns and were not pronounceable. The words were taken from among the more familiar 4-letter words appearing in the Thorndike-Lorge word count (1944). A total of 96 items of each type were prepared for use as test items, as well as 40 items of each type to be used as practice items. A patterned mask was constructed from random pieces of the letters.

The stimuli were made of Normatype Olive Demi-Gras, 12-point, black upper-case lettering centered on white 4" X 6" cards. A letter string
subtended a visual angle of 1.09° in length and .27° in height.

The stimuli were presented in a Gerbrands Harvard Model T-4A 4-field mirror tachistoscope at a viewing distance of 83.8 cm.

**Design**

Each subject participated in two sessions, one in which the stimuli were presented upside-down, and one in which the stimuli were presented right-side-up. In each session, nine blocks of 16 items, three blocks of each stimulus type, were presented. The nine blocks were arranged into three triplets, each triplet containing one block of each stimulus type. Order of presentation of stimulus type within each triplet remained constant for a given subject and was counterbalanced across subjects.

**Conditions**

Half of the subjects saw all stimuli presented in a normal right-side-up fashion in Session 1, and all stimuli presented upside-down in Session 2. For the other half of the subjects the order of sessions was reversed. The upside-down stimuli were created by simply placing the stimulus cards upside-down in the tachistoscope. Hence they were 180° rotations of the right-side-up stimuli (see Figure 2). The 48 stimuli of each type which were presented right-side-up to half of the subjects were presented upside-down to the rest of the subjects, and vice-versa.

**Practice**

At the beginning of each session the subject saw six practice blocks, two of each stimulus type. Each block contained 18 items. The practice enabled the subject to become familiar with the lettering and with the
Figure 2: The pre-exposure mask, two possible stimuli, and the post-exposure mask, Experiment 1.
procedure. During the practice trials, the experimenter adjusted the exposure duration of the stimuli so that the subject was responding at near 50% accuracy, averaged across the three stimulus types.

Procedure

The subject fixated on the center of the patterned mask (which was displayed upside-down during the upside-down session). When s/he was ready for the next trial to begin, s/he pressed a button. One half second later the mask went off and the stimulus was flashed for the pre-determined length of time. Then the mask reappeared. The subject reported the four letters that s/he saw, in left-to-right order for right-side-up stimuli and in right-to-left order for upside-down stimuli. The subject was instructed to report four letters on every trial, and to report exactly what s/he saw, even if it meant, for example, reporting a pseudoword during a word block.

Subjects

Twelve male and female undergraduates at the Massachusetts Institute of Technology served as subjects. They were paid for their participation in the 2-session experiment. Only subjects for whom the experimenter was successful in achieving an accuracy level within the range 40%-60% for each session, and whose accuracy levels for the two sessions did not differ more than 10%, were included in the study. It was necessary to run 20 subjects in order to get 12 subjects who met these requirements.

Results

Accuracy

Accuracy was measured in terms of the number of letters correctly
reported in the correct position. Total overall accuracy was 50.9% for right-side-up stimuli and 52.6% for upside-down stimuli. The experimenter was therefore successful in keeping the accuracy levels close to the desired 50% point in each condition. and the difference in accuracy between the two conditions was not significant, $F (1, 11) = 1.2$. The mean exposure durations were 46.6 msec for the right-side-up stimuli and 62.6 msec for the upside-down stimuli.

Both words and pseudowords showed a large advantage over unrelated-letter strings. Percent correct was 65.7% for words, 51.7% for pseudowords, and 37.8% for unrelated letter strings. The effect of stimulus type was highly significant, $F (2, 22) = 124.1$, p $< .001$.

The result in which we are most interested is the interaction between stimulus type and orientation. This interaction is significant, $F (2, 22) = 4.7$, p $< .025$. As can be seen from Figure 3, both the word advantage and the pseudoword advantage over unrelated-letter strings were reduced when the stimuli were presented upside-down.

Insert Figure 3 about here

Discussion

The finding that under conditions of equal overall accuracy the word superiority effect for upside-down stimuli is significantly smaller than it is for the same stimuli presented right-side-up is consistent with the encoding model of word perception. Interfering with letter identification adversely affects the encoding of higher-order units which normally causes an advantage for orthographically-regular letter strings. Can the other proposed models of word perception also account for this result?
Figure 3: Percentage of letters reported correctly in the correct position for right-side-up and upside-down stimuli, Experiment 1. W = words; PW = pseudowords; UL = unrelated letter strings; WSE = word superiority effect.
The orthographic redundancy models claim that the word superiority effect occurs because redundancy acts as an additional source of information when featural information is insufficient to produce an accurate percept of the stimulus. Thus providing interference with the extraction of featural information should not adversely affect the word superiority effect but rather should provide optimal conditions for its emergence. These models, then, cannot adequately account for the smaller word superiority effect obtained with upside-down stimuli.

Larger-unit feature models fare better than redundancy models in accounting for the results. These models claim that the word superiority effect is a function of the additional features provided by wholistic processing. Such wholistic processing tends to be greatly impaired in upside-down stimuli, and recognition of the whole in upside-down stimuli tends to rely upon recognition of the individual parts (Yin, 1970). Hence the word advantage over nonwords should not be as great for upside-down stimuli as it is for right-side up stimuli. This is the result which was found in the present experiment.

Since the present experiment did not provide exclusive support for the encoding model, additional tests of the model are required. Experiments 2 and 3 were designed to provide such evidence.
EXPERIMENT 2

Since Experiment 1 left open the possibility that larger-unit feature models, as well as encoding models, could account for the word superiority effect, the second experiment was designed chiefly to distinguish between these two types of models. In this experiment, script stimuli were compared with print stimuli.

The script word is a single, uninterrupted unit whose appearance is wholistic in nature. Furthermore, relative heights and shapes play a significant role in word identification (see Figure 4). It thus seems very reasonable to assume that whole-word shape is a useful clue to word identification for script writing. On the basis of this line of reasoning the larger-unit feature models predict an increased advantage of words over non-words for script as opposed to print stimuli.

Insert Figure 4 about here

On the other side, the encoding models predict a smaller word superiority effect for script stimuli, since script letters do not appear as distinct physical entities and are therefore more difficult to identify than print stimuli.

In addition to the comparison between script stimuli and print stimuli, this experiment also compared handwritten stimuli—both print and script—with standard typeface print and script stimuli. Because they are more variable and generally sloppier than typeface stimuli, the handwritten stimuli should create greater difficulty in letter discrimination. Like script, handwritten stimuli should reduce the word superiority effect, according to the encoding model.
Figure 4: Example of how relative size and shape of other letters in a script word can determine the identity of a letter.
East
In addition to 4-letter 1-syllable words and pseudowords and 4-letter unrelated letter strings, an equal number of 6-letter 2-syllable words and pseudowords, and 6-letter unrelated letter strings were included in this experiment. According to one model of encoding, syllabic-like units are the units of encoding. The inclusion of 2-syllable items will enable us, later in this thesis, to examine whether or not the two syllables are encoded separately, and if so, whether there is a systematic encoding of one before the other.

**Method**

**Stimuli and Apparatus**

Half of the stimuli were 6-letter strings; half were 4-letter strings. The strings were generated as follows: Twenty-four 6 letter 2-syllable words were chosen from among the most common English words according to the Thorndike-Lorge word count (1944). Six pools of letters, each containing 24 letters, were formed from the 24 words by placing all the first-position letters in pool 1, all the second-position letters in pool 2, etc. Twenty-four pseudowords were formed by taking one letter from each pool in turn, without replacement. Efforts were made to maximize the total bigram frequency count of each pseudoword, and all pseudowords were judged to be pronounceable as 2-syllable sounds by the author and an undergraduate student. Likewise, 24 unrelated letter strings were formed in the same manner, i.e. by sampling from the same pools of letters without replacement. Here, every effort was made to minimize the total bigram frequency of each string, and no strings were judged to be pronounceable. The 4-letter strings were generated in a similar manner. Twenty-four common 1-syllable 4-letter words were chosen from the Thorndike-Lorge count; twenty-four
pseudowords and 24 unrelated letter strings were formed from the four pools of letters of the words. Thus, single-letter position frequencies were identical for all three types of stimuli within each length.

All of the stimuli were prepared in four forms (see Figure 5). The **typeface print** stimuli were made of Normatype Univers 55, 20-point, black lower-case lettering. The **typeface script** stimuli were made of Chartpak Brushscript, 24-point, black lower-case lettering. The **handwritten print** stimuli were printed by an undergraduate with a somewhat sloppy handwriting. The **handwritten script** stimuli were written by the same undergraduate. A black felt-tip pen was used. The line widths of the letters of all four types of stimuli were close to identical. The person who made the handwritten stimuli wrote each letter string seven times before writing the actual stimulus to be used in the experiment. This was done to provide practice in the writing of certain uncommon letter pairs such as sr, dl, and jt, so that the letter strings would look natural. It also provided practice in writing the stimuli in exactly the same size as the typeface stimuli. All stimuli were placed in the center of a 4" X 6" white card. All subtended a visual angle of .22° in height. The 4-letter strings were approximately .90° in length; 6-letter strings were approximately 1.3° in length.

Insert Figure 5 about here

The stimuli were presented in a Gerbrands Harvard Model T-4A 4-field mirror tachistoscope.

Two patterned masks were prepared: one consisted of random pieces of the two types of press-on letters, and one was made from random segments of the handwritten letters.
Figure 5: The four types of lettering used in Experiment 2. TP =
typeface print; TS = typeface script; HP = handwritten print;
HS = handwritten script.
almost (TP)  almost (TS)

almost (HP)  almost (HS)
**Design**

There were four conditions in the between-subjects design. Twelve subjects saw only typeface print stimuli, 12 saw only typeface script stimuli, 12 saw only handwritten script stimuli, and 12 saw only handwritten print stimuli. Half of the subjects in each group saw the 6-letter strings first; half saw the 4-letter strings first. The stimuli were blocked according to stimulus type. There were 12 items in each block. Three different orders of the stimulus type were counterbalanced across subjects.

**Practice**

There were six blocks of practice items, two blocks of each stimulus type. The order of presentation of the stimulus types during practice blocks for a given subject was the same as the order of presentation for the test blocks. During the practice trials the experimenter adjusted the exposure duration of the stimuli so that the subject was reporting approximately 50% of all letters correctly, averaged over stimulus type.

**Procedure**

The pre-exposure field was occupied by the appropriate patterned mask. The subject fixated on the center of the mask. When he felt that he was fixating, he pressed a button. Five hundred milliseconds later the stimulus appeared directly in the center of the field for the pre-determined length of time. Then the stimulus was replaced by the patterned mask. The subject reported the letters that s/he saw, in left-to-right order. Four letters were required on 4-letter trials; six letters were required on 6-letter trials. The subject was encouraged to report exactly what s/he had seen, even if it was of the incorrect stimulus type. The exposure duration was
adjusted after the first cycle of three blocks if performance deviated substantially from 50%.

Subjects

The 48 subjects were male and female undergraduates at the Massachusetts Institute of Technology. They were paid for their participation in the 1-session experiment.

Results

Four-Letter Stimuli

Overall accuracy for each of the four groups lay within the range of 45.0% correct to 51.5% correct. There were no main effects of type of writing (handwritten/typeface), \( F(1, 44) = 2.4 \), or type of lettering (print/script), \( F(1, 44) = 3.4 \), \( .05 < p < .1 \). Nor was there any interaction between these two variables, \( F(1, 44) = .58 \). Thus, the experimenter succeeded in keeping the overall accuracy level of each group constant. Furthermore, the range of accuracy levels for the unrelated-letter string items was only 31.2% to 32.9%. Hence the unrelated-letter strings provide a good control against which to compare the relative advantages of the pseudowords and the words.

There was a very large main effect of letter string type, \( F(2, 88) = 416.0 \), \( p < .001 \). Total percent correct was 31.7% for unrelated letter strings, 47.3% for pseudowords, and 68.0% for words. There was a large word advantage over unrelated-letter strings, as well as a pseudoword advantage over unrelated-letter strings.

The average exposure duration needed to achieve these accuracy levels was 38.8 msec for typeface print, 69.6 msec for typeface script, 68.7 msec for handwritten print, and 97.3 msec for handwritten script. Hence the
assumption that script and handwriting each increase the difficulty of perception was supported.

The results of primary interest concern the interaction of letter string type with each of the other independent variables. There is a significant interaction of letter string type (W, PW, UL) with type of lettering (print/script) $F (2, 88) = 10.5, p < .001$. This interaction can be seen in Figure 6. It is evident from the figure that the advantage of words over unrelated-letter strings is larger for the print stimuli than it is for the script stimuli. There is also a significant interaction between letter string type and type of writing, (handwritten/typeface) $F (2, 88) = 9.6, p < .001$. This interaction is shown in Figure 7. Here we see that the word superiority effect is smaller for the handwritten stimuli than for the typeface stimuli.

**Six-Letter Stimuli**

The overall accuracy levels for the 6-letter stimuli ranged from 43.6% to 58.7%. Hence it appears that the experimenter was not so successful in keeping these levels constant across groups, although all groups did remain fairly close to the desired 50% level. The main effects of type of lettering and type of writing were both statistically significant, $F (1, 44) = 12.4, p < .005$, and $F (1, 44) = 33.6, p < .001$, respectively. However, as before, the accuracy range for the unrelated-letter strings was quite small, 25.3% to 27.1%. Relative word and pseudoword advantages can therefore be examined with the unrelated letter strings serving as a control.

Once again, there was an enormous effect of letter string type, $F (2,88) = 1,239.8, p < .0001$. Accuracy for words was 79.2%, for pseudowords it was 49.8%, and for unrelated-letter strings was 26.6%. As with the 4-letter
strings, both the word advantage over unrelated-letter strings and the pseudoword advantage over unrelated-letter strings were quite large.

The mean exposure durations that were employed for each group were 45.4 msec for typeface print, 74.0 msec for typeface script, 79.3 msec for handwritten print, and 109.2 msec for handwritten script.

Looking now at the crucial interactions, we find a significant interaction of type of writing (handwritten/typeface) with stimulus type $F(2, 88) = 25.8, p < .001$, and a significant interaction of type of lettering (print/script) with stimulus type, $F(2, 88) = 11.8, p < .001$. These interactions are graphed in Figures 8 and 9.

Insert Figures 6 and 7 here

Insert Figures 8 and 9 here

We can see in Figure 8 that the word superiority effect is smaller for script stimuli than it is for print stimuli. Both the word advantage and the pseudoword advantage over unrelated-letter strings are reduced in the script condition. Figure 9 indicates that the word superiority effect for handwritten stimuli is smaller than the effect for typeface stimuli. Again, both the word and pseudoword advantages over unrelated-letter strings are reduced in the handwritten condition.

Discussion

Once again we have obtained support for the encoding model of word perception. The two conditions which served to increase the difficulty of recognizing individual letters—script as opposed to print, and handwritten as opposed to typeface—both showed a significantly reduced word superiority effect. Can the other models account for these results?
Figures 6 & 7: Percentage of letters reported correctly in the correct position for four-letter stimuli, Experiment 2. W = words; PW = pseudowords; UL = unrelated letters; WSE = word superiority effect.

Figure 6: print and script

Figure 7: typeface and handwritten
FOUR-LETTER STIMULI

PERCENT CORRECT

W
PW
UL
PRINT

W
PW
UL
SCRIPT

WSE
WSE
Figures 8 & 9: Percentage of letters reported correctly in the correct position for six-letter stimuli, Experiment 2. W = words; PW = pseudowords; UL = unrelated letters; WSE = word superiority effect.

Figure 8: print and script
Figure 9: typeface and handwritten
As before, the situation is one in which feature extraction is made more difficult. Therefore, the orthographic redundancy models once again do not predict any decrease in the word superiority effect, since incomplete featural information provides a situation in which optimal use of redundancy should occur.

Unlike the upside-down case, in the script and handwriting cases the larger-unit feature models did not predict the obtained result. Rather these models predicted an increased advantage of words over nonwords, under the assumption that script stimuli provide more salient word-shape cues. However, an explanation of the results which is compatible with the larger-unit feature models can be formulated if a different set of assumptions is adopted. That is, it could be that the use of script stimuli, rather than creating more wholistic units, merely served to provide less familiar physical units. In that case, wholistic features would be less readily available and the present results would be those expected.
EXPERIMENT 3

In order to tease apart circumstances which increase the overall difficulty of letter identification from those which also alter the familiarity of the physical form of the stimulus, Experiment 3 was run. In this experiment, the same stimuli were used in all three conditions. Overall difficulty was increased simply by decreasing the illumination in the visual field while keeping the pre- and post- exposure fields brightly illuminated. This has the effect of reducing the contrast in the stimulus field, due to temporal summation of the illumination in the three fields. Reduced contrast should cause an increase in the difficulty of letter identification. However, overall word-shape should be relatively less affected by this manipulation than individual letters since global characteristics such as relative positions of ascenders and descendents should still be easily discerned. Hence, if this manipulation does result in a decreased word superiority effect, then only the encoding model will be able to account for this result.

Method

Stimuli and Apparatus

The stimuli were 4-letter strings, either words, pseudowords, or unrelated letter strings. The words were taken from among the more common 4-letter words listed in the Thorndike-Lorge word count (1944). The letters of the words were used to create four pools of letters, one pool for each serial position. Pseudowords and unrelated-letter strings were created from these pools of letters, so that position-specific letter frequency was identical for each of the three types of stimuli. Pseudowords were pronounceable and
adhered to the orthographic rules of the English language. Unrelated-letter strings were not pronounceable and did not have acceptable spelling patterns. An equal number of practice items of each type were also prepared.

The stimuli were made of Normatype Univers 55, 20-point, lower-case black lettering centered on white 4" X 6" cards. A letter string subtended a visual angle of .91° in length and .22° in height (without ascenders and descenders).

The stimuli were presented in a Gerbrands Harvard Model T-4A four-field mirror tachistoscope.

Design

The stimuli were blocked according to stimulus type. Each block contained 12 items. There were two test blocks of each stimulus type, and two practice blocks of each type. The six test blocks were arranged into two triplets, each triplet containing one block of each stimulus type. The six practice blocks were also arranged into triplets. The order of presentation of the stimulus types within a triplet remained constant for a given subject, and was counterbalanced across subjects.

Procedure

The subject fixated on a fixation point in the center of the visual field. When s/he was ready to begin a trial, s/he pushed a button which caused the stimulus to appear in the center of the field one half second later. The stimulus remained on for a pre-determined amount of time, then was replaced by a patterned mask made from pieces of the stimulus letters. The subject was instructed to report the letters which s/he believed s/he had seen, in left-to-right order. S/he was told not to confine answers
to the type of stimulus of which the block was composed, but rather to report exactly what s/he had seen.

**Conditions**

The subjects were divided into three groups. The experimental conditions were exactly the same for these groups with one exception: the intensity of illumination of the stimulus field was set at a different level for each group. The illumination for the high intensity group was 5.02 cd/m²; for the middle intensity group it was 1.20 cd/m²; for the low intensity group it was .37 cd/m².

**Practice**

Six practice stimulus blocks, two of each type, were presented to the subject so as to enable him to become familiar with the procedure and stimuli. During these practice blocks the experimenter adjusted the exposure duration of the stimuli until the subject was reporting approximately 50% of all letters correctly, averaged over stimulus type.

**Subjects**

Thirty-six male and female M.I.T. undergraduates were paid for their participation in the 1-session experiment. The subjects were randomly assigned to one of the three conditions.

**Results**

**Accuracy**

Accuracy was measured in terms of total number of letters correctly reported in the correct position. Overall accuracy levels for each of the three groups ranged from 46.4% correct to 51.4% correct, indicating that the experimenters were successful in keeping the overall accuracy near the
50% level for each group. There was no significant difference in overall accuracy between groups, $F(2, 33) = 2.23$. The percentage of correctly reported items was 73.7% for words, 46.9% for pseudowords, and 28.4% for unrelated-letter strings. This difference is highly significant, $F(2, 66) = 320.7, p < .0001$. Both the word and pseudoword advantages over unrelated-letter strings were quite large.

The average exposure durations employed were as follows: 42.6 msec for the high contrast condition, 81.3 msec for the middle contrast condition, and 98.9 msec for the low contrast condition.

The interaction of major interest can be seen in Figure 10. The figure indicates that as the intensity in the field grows dimmer, the word superiority effect decreases. This interaction is significant, $F(4, 66) = 3.42, p < .025$. As can be seen from the graph, reducing the illumination causes a reduction in both the word advantage and the pseudoword advantage over the unrelated-letter strings.

*Insert Figure 10 about here*

**General Discussion**

Experiments 1, 2, and 3 employed various transformations of the physical appearance of words, pseudowords, and unrelated-letter strings. In all three experiments, transformations which served to decrease the overall perceptibility of the stimuli, as indexed by the necessity of increasing the exposure duration in order to maintain a constant overall level of accuracy, appeared to have a greater detrimental effect upon orthographically-regular letter strings than upon unrelated-letter strings. This should be the case according to the encoding model, since incomplete
Figure 10: Percentage of letters reported correctly in the correct position for high, middle, and low contrast stimuli, Experiment 3. W = words; PW = pseudowords; UL = unrelated letter strings; WSE = word superiority effect.
information at the level of letter identification prevents the activation and encoding of higher-level units which contribute to the word advantage, or at least it decreases their efficiency.

No other model of word perception can account for these combined results. It must be realized, however, that other factors such as redundancy or larger-unit features may also contribute to the word superiority effect. Although those factors cannot account for the reduced word superiority effect obtained in these experiments, they may nevertheless play some role in word perception. In none of these experiments was the word superiority effect completely eliminated. It is conceivable, therefore, that the word advantage which remained was caused in part by factors such as orthographic redundancy. In fact, visual conditions which reduce the probability of detecting all the letters are just those in which one might expect redundancy to have some effect. For in the conditions in which the principles of the encoding model apply—i.e. when all letters are accurately detected at some level—there is no need for redundancy since storage and not identification of the letters is the limiting factor in accurate "perception" of all of the letters. This argument has been made for many other experimental paradigms in which the effect of context on perception is evaluated. Like redundancy models for word recognition, context has a larger influence on perception under conditions in which only partial visual information is available, when top-down processing compensates for the inadequacy of bottom-up (or data-driven) processing (e.g., Meyer, Schvaneveldt, & Ruddy, 1975).
DISTINGUISHING AMONG THE ENCODING MODELS

Now that sufficient evidence for the role of encoding in word perception has been amassed, the next task is to determine the nature of the unit that is encoded. The encoding models may be subdivided into two types, according to the proposed higher-level unit of encoding: those that consider the whole-word to be the unit of encoding, and those that consider some unit smaller than the word yet larger than the letter to be the encoding unit.

One obvious prediction of the whole-word approach under the assumption of all letters being identified before a word detector will fire is that under conditions in which a clear, brief image of the stimulus is presented, as in the right side up, typeface print, and high intensity conditions of Experiments 1, 2, and 3, respectively, either all letters in a word are reported correctly—when the word has been successfully encoded—or no letters are reported correctly—when no word has been encoded. Since, according to this prediction, no letter position should be perceived better than any other position, serial position curves for these words should be relatively flat. If, on the other hand, units such as spelling patterns or vocalic-center groups were employed in word perception the all-or-none effect would not be expected, particularly in six-letter two-syllable words which consist of several spelling patterns and two vocalic-center groups. Rather, we would expect a substantial number of partially-correct reports, reflecting the successful encoding of some, but not all, of the units. This would also be true if word detectors could fire before all letters were identified.
In addition, if the unit of encoding is different for words and unrelated letter strings, which is the claim of all encoding models, then the shapes of the serial position curves for unrelated letter strings and words should be different, reflecting the difference in encoding strategies. For unrelated-letter strings the serial position curves should reflect an encoding strategy employed in encoding each letter individually. For example, if the letters are encoded in left-to-right order, the curve would be monotonically-decreasing. If the letters are encoded in an ends-first manner, the curve would be U-shaped.

Pseudoword curves should resemble word curves if the spelling-pattern is the unit of encoding, since both words and pseudowords are composed of such patterns. If the word is encoded as a whole unit, however, then pseudoword curves may look like word curves if they, too, are encoded as single units. Or, they may look different if some other means of encoding is employed for pseudowords (as spelling patterns).

What about the serial position curves for words for which a clear image is not presented? These would be the words in the upside-down, handwritten, script, and low intensity conditions of Experiments 1, 2, and 3, respectively. We expect these curves to begin to take on the characteristics of the unrelated letter string curves, whatever those characteristics are. This should happen because introducing increased variability in letter identification should result in more instances of failure to identify a word, forcing encoding of individual letters.

These predictions may be tested by plotting the results of Experiments 1, 2, and 3 according to serial position. These plots are presented in Figures 11-13.
SERIAL POSITION CURVES

Experiment 1

A graph of the percentage of letters reported correctly in each serial position of the stimulus for each stimulus type in Experiment 1 is presented in Figure 11. Both right-side-up and upside-down unrelated-letter strings show a V-shaped curve, although the V is more exaggerated in the upside-down condition. It should be noted that serial position 1 represents the right-most position for the upside-down stimuli while it represents the left-most position for the right-side-up stimuli. Thus, the fact that the two curves are nearly the same shape suggests the curves result from some sort of processing or encoding strategy and not purely visual conditions.

The pseudoword curves are less clear. The upside-down curve shows a somewhat distorted V shape, while the right-side-up pseudowords produce a similar, albeit flatter curve.

For word stimuli the upside-down curve appears similar to that for the pseudoword stimuli. The right-side-up word curve shows positions 1 and 2 to be roughly equal and positions 2 and 4 to be roughly equal, giving the appearance of a zig-zag flat curve.

 Insert Figure 11 about here

Trend analyses performed on these data yielded significant linear trends for the upside-down word and pseudoword curves and for both unrelated-letter string curves. These trends suggest a left-to-right encoding strategy for all upside-down stimuli and for right-side-up unrelated-letter strings. No such trend was found for right-side-up words or pseudowords.
Figure 11: Percentage of letters reported correctly broken down by serial position, Experiment 1.
Additionally, a quadratic trend emerged for the upside-down unrelated-letter strings, suggesting an ends-first encoding strategy mixed with the left-right strategy.

**Experiment 2**

The data for Experiment 2 were analyzed according to the number of letters reported correctly in each of the four positions of the four-letter stimuli and in each of the six positions of the six-letter stimuli, broken down by stimulus type. The results are presented in Figures 12 and 13, respectively.

*Insert Figures 12 and 13 about here*

The separation of the four curves of the word stimuli in Figures 12 and 13 and the separation of the four pseudowords curves in Figure 13 reflect the interactions discussed earlier, which were more clearly seen in Figures 6 through 9. The patterns we are concerned with here are not the positions of the curves but rather the shapes of the curves.

All of the unrelated-letter string curves exhibit the same U-shaped pattern, indicating that the initial and final letters of the stimuli were reported correctly far more often than the middle letters. The pattern is similar for the pseudoword stimuli, although the U shape is not as steep. In the case of the six-letter pseudowords, the initial position shows a marked advantage over the final position, which shows an advantage over the middle positions.

Trend analyses revealed significant quadratic effects for all unrelated-letter string curves and for all pseudoword curves except for the 4-letter typeface print pseudoword curve. In addition, six of the eight unrelated-
Figures 12 & 13: Percentage of letters reported correctly broken down by serial position, Experiment 2.

Figure 12: four-letter items

Figure 13: six-letter items
letter string curves and six of the eight pseudoword curves showed significant linear trends as well. These results suggest that a left-to-right encoding strategy is usually combined with an ends-first encoding strategy for pseudowords and unrelated-letter strings.

The most interesting pattern of results is found in the word curves. Here we see attenuated U-shaped curves for the more difficult stimulus types, but an actual flattening of the curves for the easier-to-discriminate stimulus types. The curves for both the four-letter and six-letter typeface print stimuli are practically flat, indicating that all positions within the stimulus were seen equally well.

Statistical analyses confirm these observations. While neither the four-letter nor the six-letter typeface print word curves show any evidence of a quadratic trend, all of the other word curves do show significant quadratic trends. A significant linear trend was found only for the six-letter handwritten script words.

**Experiment 3**

Serial position curves for Experiment 3 are presented in Figure 14. The separation of the curves within stimulus type reflects the interactions discussed earlier. Again, the patterns of interest in these curves are the shapes of the curves.

For the unrelated-letter strings of all conditions the curves take on the shape of an exaggerated U. This represents the fact that letters in the first position were reported correctly more often than those in the last position, which in turn were reported correctly more often than those in the middle two positions. The pseudoword curves show a similar pattern,
although not as severe.

There were statistically significant quadratic trends for all unrelated-letter string curves, and significant linear trends for two of the three curves. The low-contrast pseudoword curve showed a significant quadratic trend; the high-contrast curve showed a significant linear trend; the middle contrast curve showed both quadratic and linear trends.

The word curves for the middle and low intensity items show an attenuated U-shaped curve. However, the word curve for the high-intensity items does not show any resemblance to the U-shaped curves. Rather, this curve is virtually flat, demonstrating that all letter positions are perceived accurately equally often when the word stimulus is well-illuminated.

Trend analyses revealed significant quadratic effects for the middle and low intensity words, but no such trend for the high intensity words. The middle intensity word curve showed a small but significant linear trend as well.

Discussion

Additional Support for Encoding Models

The serial position curves for Experiments 1, 2, and 3 taken together provide further supporting evidence for the encoding models. In all cases, the curves for the unrelated-letter strings were of a different shape than the curves for words, suggesting a difference in encoding strategies. All curves for unrelated-letter strings were roughly U-shaped, a pattern suggestive of an ends-first strategy of encoding. The word curves, on the other hand, were flat, or nearly so, a pattern which is highly suggestive
Figure 14: Percentage of letters reported correctly broken down by serial position, Experiment 3.
of single-unit as opposed to letter-by-letter encoding.

The pseudoword curves fall in between the word and unrelated-letter string curves, being more U-shaped than the flat word curves and less severely U-shaped than the unrelated-letter string curves. The most plausible explanation of this finding is that pseudowords are sometimes encoded as single units, producing flat curves, but sometimes they are encoded letter-by-letter, producing U-shaped curves. When a flat curve is combined with a U-shaped curve the result is an attenuated U-shaped curve.

The word stimuli which are presented under less-than-optimal conditions, as predicted by the model, are not flat but are somewhat U-shaped like the unrelated-letter string curves. This indicates that interfering with visual conditions sometimes prevents the use of encoding higher-level units, forcing words to be encoded like random letter strings, one letter at a time. Since under these conditions only some of the letters are actually identified (prior to encoding) the U shape curve may also reflect, to some extent, more accurate identification of the outer letters due to lateral masking of the inner letters.

Support for the Word as a Single Unit

The finding of flat serial position curves for clearly-presented word stimuli provides support for encoding models which postulate the whole word as the unit of encoding. If the entire word is encoded as a unit, no one position is perceived better than any other position. If words were being encoded as groups of higher-order units such as spelling patterns, then such flat curves would not be expected unless such units, occurring at
different positions within words, were correctly encoded equally often, averaged over all words. Such a possibility is unlikely since it implies random encoding rather than the use of some optimal encoding strategy.

However, it is still possible that the subjects are encoding in a random rather than optimal order. In order to check this possibility, an examination of the total number of correctly-reported letters per item was made. That is, how often was an item reported entirely correctly? How often was one letter missed? Two letters? All of the letters? If words are encoded as whole units, then in the majority of cases either all of the letters or none of the letters should be reported correctly. If spelling patterns or vocalic center groups are the units of encoding employed, then there should be a large number of cases in which only two or three letters are reported correctly.

As can be seen in the left panel of Figures 15-18, in the vast majority of cases for clearly-presented words all of the letters were reported correctly. The second largest category is that in which none of the letters were reported correctly. Therefore support for the word as a unit of encoding remains strong.

Insert Figures 15-18 about here

There is one problem with the current interpretation of the serial position curves. Thus far, all experiments were run at a 50%
Figures 15 - 18: Percentage of items in which 0, 1, 2, 3, 4, (5, 6) letters were reported correctly.

Figure 15: Experiment 1

Figure 16: Experiment 2, four-letter items

Figure 17: Experiment 2, six-letter items

Figure 18: Experiment 3
accuracy level, averaged across the three stimulus types. This meant that the word stimuli were always reported with a very high degree of accuracy, the pseudowords were reported at around 50% accuracy, and the unrelated letter strings were reported at a very low level of accuracy. Thus it is possible that the shape of the serial position curve is a function of the accuracy level at which the particular stimulus type is reported. That is, the flatter word curves may be explained as follows: As accuracy increases, the greatest improvement is seen in the middle positions, since those positions have the greatest room for improvement. In other words, the flattening of the curves as accuracy increases may be something of a ceiling effect. Analogously, the finding that in most instances all the letters of a word are reported correctly may also be a ceiling effect.

In order to test this alternative explanation of the serial position curves, another experiment was run. In this experiment the possible artifact was eliminated by running all three stimulus types at a 50% accuracy level. If the artifactual explanation of the serial position curves is correct, then the shapes of the curves for all three stimulus types should be identical. If, however, the curves really do reflect the encoding process outlined above, then the curves for clearly-presented word stimuli should still be flat, even at this 50% accuracy level.

In addition, the stimuli will be examined for the number of trials in which all letters are reported correctly or all letters are reported incorrectly. As before, if the flat serial position curves
represent all-or-none encoding, then these trials should constitute
the majority of all word trials. If they do not, then the flat curves
may be the result of a cancellation effect—i.e. on some trials the
first letter-cluster is reported correctly while on other trials the
last letter-cluster is reported correctly.
EXPERIMENT 4

Method

Stimuli and Apparatus

The stimuli used in this experiment consisted of the same 6-letter words, pseudowords, and unrelated-letter strings used in Experiment 2. There were two conditions: typeface print and handwritten print. The typeface print stimuli were constructed from Normatype Univers 55, 20-point, lower-case black lettering. The handwritten print stimuli were written by an undergraduate whose handwriting was similar to that used in the analogous condition in Experiment 2. All stimuli were centered on white 4" X 6" index cards. Each 6-letter string subtended a visual angle of .22° in height and approximately 1.3° in length.

The stimuli were presented in a Gerbrands Harvard Model T-4A four-field mirror tachistoscope.

In addition to the two blocks of practice stimuli of each stimulus type used in Experiment 2, an additional six blocks were prepared, two of each stimulus type.

Design

Six subjects were run in each of the two conditions, typeface print and handwritten print. For all subjects, the experimental session was divided into thirds. During each third of the session, the subject saw only one stimulus type. The order of presentation of the three stimulus types was counterbalanced across subjects.
Practice

At the beginning of each third of the session the subject was presented with four blocks of practice items of the appropriate stimulus type. During this time the experimenter set the exposure duration of the stimuli so that the subject was reporting approximately 50% of the letters correctly. A new exposure duration was determined for each stimulus type so that all three stimulus types were run at approximately 50% accuracy.

Procedure

The subject fixated on the fixation point. When he was ready for a trial, he pressed a button which caused the stimulus to appear 500 msec later for the pre-determined amount of time. The subjects reported the letters that they thought they saw, in left-to-right order. A six-letter response was required on all trials.

Subjects

Since the purpose of this experiment was to compare the serial position curves of the three stimulus types under the two different conditions when overall accuracy was roughly equal, only those subjects whose accuracy levels for all three stimulus types remained within the 40%-60% range were kept in the experiment. A total of 21 subjects were run in order to get the 12 subjects needed for the experiment. All were M.I.T. undergraduates who were paid for their participation in the 1-hour session.
Results

Accuracy

The accuracy levels for the six conditions (three stimulus types X two writing conditions) ranged from 44%-53%, which is a sufficiently small range so that any other differences between conditions could not convincingly be explained as being a consequence of accuracy level. The average exposure durations used to achieve these accuracy levels for the typeface print stimuli were as follows: words, 35.2 msec; pseudowords, 42.8 msec; unrelated letter strings, 85.7 msec. For the handwritten print stimuli the average exposure durations were as follows: words, 48.4 msec; pseudowords, 70.1 msec; unrelated letter strings, 119.3 msec.

Serial position curves

Serial position curves for the six conditions are presented in Figure 19. The curves for the unrelated letter strings look remarkably similar to those of Experiment 2, although the center of the U-shaped curve has been raised considerably. Likewise, the pseudoword curves show an attenuated U-shape, as in Experiment 2, with the U-shape of the handwritten pseudowords steeper than that of the typeface pseudowords. The word curves, although moved down considerably on the overall scale, nonetheless show the same pattern seen in Experiment 2: While the curve for handwritten words takes on an attenuated U-shape, the curve for the typeface words remains virtually flat.

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Insert Figure 19 about here
Figure 19: Percentage of letters reported correctly broken down by serial position, Experiment 4.
Trend analyses revealed significant quadratic and linear effects for both unrelated-letter string curves. There was a significant quadratic effect for handwritten words but none for typeface words. There was a significant quadratic effect for handwritten pseudowords as well. The typeface pseudowords showed a small but non-significant quadratic trend. There were no linear effects for any of the word or pseudoword curves.

Figure 20 presents the average percentage of words, pseudowords, and unrelated-letter strings in which the subject reported 0, 1, 2, 3, 4, 5, or 6 letters correctly. As can be seen from the graph, few unrelated-letter strings were reported entirely correctly. In addition, equally few were missed entirely. The 50% overall accuracy level reflects the fact that for most unrelated-letter strings, 2, 3, or 4 out of 6 letters were reported correctly.

The inverted U-shape of the unrelated-letter string curves is less severe for the pseudoword curves. More strings are reported entirely correctly or entirely incorrectly for pseudowords than for unrelated-letter strings. The typeface pseudowords show even less of a U-shape than the handwritten pseudowords.

The curves for the word stimuli are complete rotations of the curves for unrelated letters; they are upright U's, not inverted U's. For the word stimuli the 50% accuracy level is primarily the result of the majority of stimuli being reported either entirely correctly or entirely incorrectly. This pattern is somewhat weaker for the handwritten words than for the typeface words. There appear to be
substantially more instances of two or three letters out of six being reported correctly for the handwritten as opposed to the typeface words.

Insert Figure 20 about here

Discussion

The results of Experiment 4 and the analyses of serial position curves for Experiments 1, 2, and 3 demonstrate that when a word is presented clearly for a brief period of time, then if any letters at all are reported correctly it is probable that all of the letters will be reported correctly. These results, then, provide overwhelming support for an encoding model of word perception in which the whole word is the encoding unit. In addition, the results support the postulate that all letters must be identified before a word detector will fire.

If the word advantage over unrelated letter strings is the result of an encoding process based upon the whole word, then it remains to explain why pseudowords, too, are usually reported more accurately than unrelated letter strings. An explanation of the orthographic effect will be proposed shortly, but first a fifth experiment bearing on the issue of encoding in word perception will be discussed.
Figure 20: Percentage of items in which 1, 2, 3, 4, 5, or 6 letters were reported correctly, Experiment 4.
THE EFFECTS OF EXPECTATION ON ENCODING

EXPERIMENT 5

In discussing the role of encoding in the word superiority effect during the course of this thesis, the word advantage has occasionally been referred to as an advantage in encoding "strategy". In the final experiment we will explore the extent to which this encoding strategy is indeed a strategy. That is, we will examine the degree of control, if any, which the perceiver has in employing various encoding strategies, and the degree to which such strategies are automatic processes (see LaBerge & Samuels, 1974). One way to vary the likelihood that different encoding strategies will be employed, if such strategies are indeed controllable to any extent, is to vary the subjects' expectations of what types of stimuli will be presented. The following experiment employed such a manipulation.

Method

Stimuli and Apparatus

The stimuli used in this experiment were the same four-letter words, pseudowords, and unrelated letter strings used in Experiment 3.

Design

The test stimuli were divided into four different types of lists, each list containing 18 items. List 1, the equal list, contained six words, six pseudowords, and six unrelated letter strings. List 2, the mostly words list, contained 12 words, 3 pseudowords, and 3 unrelated letter strings. List 3, the mostly pseudowords list, contained 3 words,
12 pseudowords, and 3 unrelated letter strings. List 4, the mostly unrelated letter strings list, contained 3 words, 3 pseudowords, and 12 unrelated letter strings. The stimuli were randomly arranged within each list.

Although all subjects saw the same 24 words, pseudowords, and unrelated letter strings, the specific items which appeared within each list were rearranged four times during the course of the experiment so that every six subjects saw a different version of the four lists. For each of the six subjects viewing a particular group of lists, the order of presentation of the four lists was different.

**Practice**

Six practice blocks were presented for the purpose of familiarizing the subject with the procedure and stimulus types. The practice items were blocked by stimulus type. The six practice blocks were arranged into triplets, each triplet containing one block of each stimulus type. The order of presentation of stimulus type within a triplet was counterbalanced across subjects. During the practice trials the experimenter adjusted the exposure duration of the stimuli until the subject was reporting approximately 50% of all letters correctly, averaged over stimulus type.

**Procedure**

Before each list was presented, the subject was told the nature of the list s/he was about to see. For the equal list, the subject was told that there would be an equal number of words, pseudowords, and unrelated letter strings appearing within the list. For the
most mostly words list the subject was told that the list would contain mostly words, but that there would be a few pseudowords and a few unrelated letter strings. The exact number of words, pseudowords, and unrelated letter strings to appear was not disclosed. Analogous information was provided before the start of lists 3 and 4.

All four lists were presented at the same exposure duration, as determined during the practice trials. The mean exposure duration was 46.3 msec.

The procedure was otherwise the same as that of Experiment 3.

Subjects

Twenty-four male and female members of the M.I.T. community each viewed all four types of lists in one experimental session. They were paid for their participation.

Results

The results were analyzed both by the number of items reported completely correct and by the total number of letters correct. The analyses were broken down by stimulus type within a given list. The results can be seen in Table 1.

There was a significant effect of stimulus type for both measures, $F(2, 46) = 165.7, p < .001$ for number of items completely correct, and $F(2, 46) = 145.8, p < .001$ for number of letters correct. There was also a significant effect of list, $F(3, 69) = 13.5, p < .001$, and $F(3, 69) = 10.2, p < .001$, respectively. A significant stimulus type by list interaction also emerged, $F(6, 138) = 7.0, p < .001$, and $F(6, 138) = 4.96, p < .001$. 
Closer examination of the data indicates that the interaction is caused by a large drop in accuracy on words and pseudowords when they occur within the list containing mostly unrelated letters. Accuracy on words and pseudowords remains constant within the other three types of lists. Such a discrepancy does not occur for unrelated letter strings, which are reported equally well (or equally poorly) on all four types of lists.

The Dunnett test was used to provide a statistical test of performance on the three biased lists, for each stimulus type, compared with performance of the list in which all stimulus types occurred equally often. For words, accuracy on the mostly-unrelated-letters list differed significantly from accuracy on the equal list on both measures, \( p < .01 \). For pseudowords, accuracy on the mostly-unrelated-letters list differed significantly from accuracy on the equal list, \( p < .01 \), on the measure of number of letters reported correctly. The difference on the measure of number of items completely correct, although in the right direction, did not reach significance.

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Insert Table 1 about here

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For all other comparisons of biased lists with the equal list involving words and pseudowords, and for all comparisons involving unrelated letter strings, significance levels of .05 were not reached.

One further question arose from examination of the data. That is, did the use of a mostly-unrelated-letters list actually succeed
Table 1
Percent Correct Responses by List for Each Stimulus Type
Experiment 5

<table>
<thead>
<tr>
<th>Stimulus Type</th>
<th>Equal</th>
<th>Mostly Words</th>
<th>Mostly PW's</th>
<th>Mostly UL's</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items Completely Correct</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Words</td>
<td>63.9</td>
<td>65.3</td>
<td>65.3</td>
<td>33.3</td>
</tr>
<tr>
<td>Pseudowords</td>
<td>18.1</td>
<td>20.8</td>
<td>19.4</td>
<td>11.1</td>
</tr>
<tr>
<td>Unrelated Letters</td>
<td>2.1</td>
<td>0.0</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Total Letters Correct</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Words</td>
<td>76.2</td>
<td>75.9</td>
<td>76.4</td>
<td>53.8</td>
</tr>
<tr>
<td>Pseudowords</td>
<td>58.3</td>
<td>59.7</td>
<td>51.2</td>
<td>45.5</td>
</tr>
<tr>
<td>Unrelated Letters</td>
<td>33.5</td>
<td>29.9</td>
<td>37.5</td>
<td>32.4</td>
</tr>
</tbody>
</table>
in eliminating the word superiority effect? Analysis of variance indicated that the pseudoword advantage over unrelated letter strings remained significant for both measures, $F(1, 23) = 7.41, p < .025$ and $F(1, 23) = 13.92, p < .005$ for items correct and letters correct respectively, although the word advantage over pseudowords was significant for items correct, $F(1, 23) = 8.98, p < .01$ but not for letters correct, $F(1, 23) = 1.96, p > .1$.

**Discussion**

There are several interesting observations to be made concerning these data, the most general of which is that expectation of the type of letter string to be presented can significantly alter the accuracy with which that letter string is reported. More specifically, the expectation of unrelated letter strings alters accuracy on both words and pseudowords. Such a finding cannot be explained in terms of the tendancy to guess the type of letter string which is expected, for if this were the case then accuracy on word trials would decrease when pseudowords were expected, and accuracy on pseudoword trials would decrease when word trials were expected. However, there was no tendancy whatsoever for this to occur. These effects suggest that encoding strategies vary with expectancy. Whether or not this change in strategy is under conscious control remains unanswered for the present time. Introspective reports, which would have been of value in answering this question, were not obtained.

The results further suggest that the encoding strategies used for words and pseudowords are the same or indeed are very similar while
the encoding used for unrelated letter strings is quite different. This idea will be pursued further in the general discussion of pseudo-word perception below.

Another interesting finding is that perception of unrelated letter strings is not adversely affected by the expectation of words or pseudowords. This finding makes sense if we suppose that the encoding of individual letters is a strategy which is always employed, regardless of the stimulus expected. The encoding process which results in the word and pseudoword advantage is one which is employed in addition to the strategy of encoding individual letters. That these two encoding processes occur in parallel when orthographically-regular stimuli are expected fits well with the finding that the visually-degraded word stimuli show somewhat U-shaped serial position curves. Although attempts to encode the stimulus as a higher unit may fail, the stimulus is simultaneously being encoded as a string of letters; hence partially-correct reports occur.

Finally, there is a strong suggestion that the encoding of higher-level units contains an automatic component, since the word superiority effect is not eliminated when unrelated letter strings are expected. An alternative explanation of this result is that subjects occasionally switched strategies during the mostly unrelated letter string list.
Pseudoword Perception

The results of Experiment 4 have suggested that when a brief, clear visual image of a word is presented, the word is normally perceived as a single unit, if it is perceived at all. But if words are perceived more accurately than nonwords because they can be matched as a single unit to a unit which already exists in long-term memory, then how can we explain the advantage of orthographically-regular nonwords over letter strings which do not follow the rules of English orthography? Such pseudowords cannot be matched to units in long-term memory, for they have probably never been encountered before and would therefore not be stored in long-term memory.

The most obvious explanation, and the one most commonly put forth to account for the effects of orthographic structure, is that for pseudowords the unit of encoding is the letter cluster or spelling pattern (Gibson et al., 1962). Although evidence is against the use of letter clusters in encoding real words, pseudowords do not show the all-or-none pattern characteristic of words, or at least not to the same degree, and hence are still open to the spelling-pattern hypothesis.

One problem with this hypothesis, as pointed out by McClelland & Johnston (1977), is that several studies (Manelis, 1974; McClelland & Johnston, 1977) have failed to find any effect of bigram frequency. That is, although frequent words are perceived more accurately than infrequent words (Howes & Solomon, 1951; Solomon & Howes, 1951), pseudowords composed of frequent bigrams are not perceived any better
than low bigram frequency pseudowords. If perceived letter clusters were indeed being matched to letter clusters in long-term memory, then we should expect those letter clusters which occur more frequently to be more readily matched, just as words which occur more frequently are more readily matched. The failure to find such a correspondence for bigrams is a problem which needs to be explained by proponents of the letter cluster or spelling-pattern hypotheses.

The alternative proposed by McClelland & Johnston (1977) is that higher-level representations of pseudowords, rather than being activated, are constructed under the guidance of certain rules. The result of such construction may be, for example, some sort of sequence of phonological codes, the combination of which would be a pronounceable unit. It is further suggested by McClelland & Johnston (1977) that words are perceived as a result of two processes occurring in parallel. Words may be perceived as the result of activation of codes in long-term memory, while at the same time the construction of a phonological code may take place. The results of Experiment 5 bear directly on several predictions of this model. First, if both the processes of construction and of matching units in long-term memory occur during word perception, then when words are expected pseudoword perception should not be hurt, since pseudowords are encoded by means of the construction process. This is indeed borne out by the data. There is no difference in accuracy of report of pseudowords for the list in which words were expected and the list in which pseudowords were expected. A second prediction of such a model is that when pseudowords are expected
accuracy of word perception would decrease relative to the accuracy when words are expected. This would be the case because only one of the two means of processing words, construction, would be employed when pseudowords were expected. This prediction is not borne out by the data. Words are perceived just as well when pseudowords are expected as they are when words are expected.

What we have, then, is a situation in which the expectation of either words or pseudowords produces optimal conditions for the perception of either type of stimulus while the expectation of unrelated letter strings adversely affects perception of both words and pseudowords. Such a situation suggests that different processing strategies may be invoked, depending on expectation, and that words and pseudowords may be processed in a like manner. What are the candidates for such a mode of processing?

It is possible that both words and pseudowords are processed by means of construction. However, as we noted earlier, words appear to be recognized in an all-or-none fashion. Construction of a sequence of phonological codes would not predict such an outcome, for there should be many instances in which the construction is only partially completed, resulting in a partially correct report.

An alternative is that both words and pseudowords are matched to codes in long-term memory. There is much support for this in the case of words in the literature on the word-frequency effect (Solomon & Postman, 1952), but how might this possibly occur for pseudowords? Surely there exist no codes for pseudowords in long-term memory. One
possibility is that when a pseudoword is presented long-term memory is searched for a word which most closely approximates the pseudoword. When it is found, any discrepancies between it and the visual stimulus are noted, time permitting. For example, the pseudoword *kest* may be encoded as *best* with a *k* instead of a *b*.

Is there any support for such a model? Some indirect support comes from a recent paper by Glushko & Rumelhart (Note 1). They found that when a pseudoword is presented briefly and the subject's task is to pronounce the pseudoword as quickly as possibly using the first acceptable pronunciation that comes to mind, subjects often provide pronunciations that are analogous to the pronunciations of similar real words, even if such pronunciations are not those which would normally be constructed on the basis of spelling-to-sound correspondence rules. Hence *mave* might be pronounced *mav* rather than *may*, just as *have* is pronounced *hav*. Thus it appears that in pronouncing a novel pseudoword, the subject often appeals to the pronunciations of existing words in long-term memory, rather than constructing sounds based upon rules. While Glushko & Rumelhart's pronunciation task is a different task from the letter string perception task under consideration, the use of such a strategy in pronunciation certainly lends credence to the possibility that a similar strategy may occur in perception.

This explanation fits well with Pillsbury's (1897) observation that subjects are often most sure of having seen letters which weren't even there. Pillsbury appeals to the notion of "general word shape" as an
explanation. However, a similar observation in the data of Experiment 5 cannot be explained in such a manner. That is, in the list in which pseudowords were expected, the pseudoword juge was reported as jude four times and as judge two times, while being reported correctly only three times. Why did this d turn up half of the time? It is very likely that the subjects who "saw" the d had matched juge to the word judge in long-term memory. (In fact, several subjects insisted that they had seen the word judge.) Then, being forced with the requirement to report only four letters, they dropped the last letter, e, or occasionally the next-to-last letter, g (which left them with a true pseudoword). It should be noted that general word-shape could not explain why the subjects saw the word judge. Since these stimuli were printed in lower-case type, a d would have had an ascender; yet clearly no ascender was present in the item juge. The likely explanation is that the sequence of letters j-u-g-e is more similar to the sequence of letters in the word judge than to any other word, and it was on the basis of the initial letter identification that the word judge was located.
Overview

A more detailed version of the model depicted in Figure 1, which is based upon the results presented in this thesis and the interpretation of these results, is presented in Figure 21. As with many models, the first stage is feature extraction. At this stage features of individual letters are extracted from the physical stimulus.

Insert Figure 21 about here

The next stage is letter identification. At this stage a letter identity is assigned to each letter position on the basis of the features which have been extracted. If the stimulus is brief and clear, the letters of words, pseudowords, and unrelated letter strings are identified equally well at this stage. Identification of the letters does not necessarily mean that they are available for report. Rather, it simply indicates that the activation of letter detectors can provide input to the next stage of perceptual processing (see Estes, 1975).

The processing which occurs at the next level depends upon the type of stimulus the subject is expecting. If s/he is expecting a word, as will normally be the case, then the letter sequence which has been identified in the preceding stage is compared with words in memory until a suitable match is achieved. Once matched, the word, which exists as a single unit in memory, may be encoded as a single unit.
Figure 21: An encoding model of word perception.
letter encoding

letter identification

feature extraction

physical stimulus

encode word and any discrepancies

match to word in LTM, Note any discrepancies

expect orthographically-regular stimuli

response

"sock" or "sock" or smelly footwear

"SOCK"

"S" "0" "C" "K"

SOCK

SOCK
The exact nature of the word code is unspecified. Any of a number of codes is possible: visual codes, verbal codes, acoustic codes, conceptual codes, or even a mixture of many codes. It is not within the scope of this thesis to discuss the nature of representation in long-term memory. However, specification of the code employed is not crucial to the main arguments presented here. Additionally, while the word is being encoded, the individual letters themselves are being encoded in an ends-first manner, a process which takes more time since there are more units to encode.

If the stimulus is not a word but a pseudoword, then the word which most closely matches the stimulus is found. Then, time permitting, differences between the matched word and the stimulus are noted. If the stimulus is an unrelated letter string, words which are similar will not likely be found. Hence, the letters will only be encoded individually.

If a pseudoword is expected, the same basic processes will occur. If, on the other hand, an unrelated letter string is expected, no search through long-term memory for a word will occur in most cases, but rather emphasis will be placed upon encoding the individual letters of the stimulus.

The above model places the locus of the word-superiority effect at the level of encoding. Unrelated letter strings are encoded one letter at a time. Hence the number of units to be encoded equals the number of letters in the string. Words and pseudowords, on the other hand, can be encoded on the basis of a match between the identities of
the stimulus letters and an identical or nearly identical set of letter identities which exist as a unit in long-term memory. When such a unit is activated, it can be encoded as a single unit (with a description of any discrepancy which might exist between the stimulus and the word in long-term memory). The word-superiority effect is the result of the relative efficiency of encoding one unit (a word) as opposed to several units (letters).

Activation of these higher-level units in long-term memory is dependent upon the prior identification of all of the letters in the stimulus. Degradation of the stimulus, as in the first series of experiments in this thesis, has its locus of effect at the stage between feature extraction and letter identification. Presenting a stimulus of poor visual quality increases the variability in the amount of time needed to identify each letter; some letters will be readily identified while the identities of others remain obscure. Incomplete identification of all of the letters precludes activation of the higher-level unit detectors, eliminating the encoding advantage which words and pseudowords normally enjoy over unrelated letter strings. All stimuli must therefore be encoded letter-by-letter. The U-shaped curves in this situation come about partly as a result of an ends-first encoding strategy, but may also reflect the inferior perception of the middle letters which may be caused by their having letters on both sides contributing to lateral interference while end letters only have a letter on one side.
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threshold and its independence of stimulus frequency. Journal of Exper-  


Footnote

1 An alternative encoding model is one in which larger-unit detectors are activated directly by the output from the feature detectors. To the extent that fewer features are needed to activate a larger-unit detector than the component letters this formulation becomes a redundancy model. If, on the other hand, the same features are required to activate a larger-unit detector directly as are needed to activate the individual letters, then the issue of whether letter detectors are actually activated or are simply passed over is impossible to resolve. However, it does seem more plausible that letter identification occurs for reasons discussed earlier, namely: 1) it is far more efficient to store many different feature sets (corresponding to different type fonts and cases) for 26 letters than to store such sets for 50,000 words, and 2) mixed-case words, for which surely no feature sets should exist in long-term memory, can be perceived much better than mixed-case pseudowords or unrelated letters. Consequently, the encoding model which will be entertained is one in which letter detectors are activated prior to the activation of higher-level units.
i: stimuli used in experiment 1

ii: stimuli used in experiments 2-5

experiment 2: all stimuli

experiment 3: four-letter stimuli only

experiment 4: six-letter stimuli only

experiment 5: four-letter stimuli only
<table>
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<tr>
<th>WORDS</th>
<th>PSEUDOWORDS</th>
<th>UNRELATED LETTERS</th>
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