ORTHOGRAPHIC AND PHONEMIC CODING FOR WORD IDENTIFICATION: EVIDENCE FROM HEBREW

Shlomo Bentin, Neta Bargai, Amiram Carmon, and Leonard Katz++

Abstract. In Hebrew script, vowels are represented by small dots that are added to the consonants. In most printed material the dots are omitted, so that the reader sees only consonant strings. Because several different words (with different vowel structures) can share the same consonant string, a unique pronunciation for such a string is determined by the syntactic and semantic contexts. The purpose of this study was to investigate the influence of this phonemically ambiguous script on the reader's use of phonemic information for printed word recognition. In the first experiment, subjects were asked to name, as fast as possible, isolated words presented as consonant strings without vowels. Naming was faster when a single lexically valid pronunciation was possible than when the stimulus could be pronounced in several ways. In contrast, in the second experiment, the same phonemic ambiguity did not interfere with lexical decision, suggesting that phonemic codes were not used for printed word recognition. This suggestion was further investigated in a subsequent lexical decision task in which all consonant strings (words and nonwords) were presented with the vowel dots. There were three groups of nonwords: (1) the nonwords were homophonous to real words but, because of one different consonant, looked different; (2) the nonwords were made up of the same consonants as real words (orthographically similar) but, because of different vowels, sounded different; (3) the nonwords were neither phonemically nor orthographically similar to real words. Response time was fastest for the totally dissimilar nonwords and longest for the orthographically similar nonwords. Presumably, graphemic information provided by the print was more important than phonemic information in partially activating real word lexical entries and, thereby, slowing rejection of the orthographically similar nonwords. In contrast, those real words that had been primed by phonemically or orthographically similar nonwords were facilitated equally by both. This equality suggests that the priming effect had been mediated by those same real words that had been activated in the lexicon by the similar nonword primes. Several implications for models of printed word recognition are discussed.

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The present study was concerned with the process of printed word recognition and with the way in which print is related to the representation of words in the internal lexicon. A close relationship should exist between the nature of the phonological information provided by an orthography and the way the print maps onto the internal lexicon. For example, the Serbo-Croatian spelling system keeps an isomorphic relationship between letters and phonemes; letter-to-phoneme translation is therefore straightforward and requires minimal contextual linguistic information. It might seem reasonable to suggest, therefore, that phonemic codes mediate between print and the lexical item it represents. On the other hand, English spelling most often represents the morphophonemic level rather than the phonemic; the invariance in meaning between words is represented by an invariant spelling in spite of changes in phonemics (as in "heal-health" and "decagram-decimal"). This makes the rules for letter-to-phoneme translation more complex and indirect, suggesting that phonemic codes may be less often used by the skilled English reader. It seems plausible that skilled reading in English and Serbo-Croatian are efficient processes because the behavior is a well-exercised one. However, what is efficient for one orthography is not necessarily efficient for the other.

Differences in the reading process between Serbo-Croatian and English may be particularly strong in the subprocess that is involved in word identification, because it is here that the two orthographies differ most. Word identification is most often studied in the laboratory by means of the lexical decision task. It has been suggested that the major factor determining a skilled reader's use of phonemic recoding in making a lexical decision is the directness with which the reader's orthography maps onto the phonemic space of his/her language (Feldman & Turvey, in press; Katz & Feldman, 1982). Indeed, the evidence presented by Feldman and Turvey (in press), strongly supports the notion that printed word identification in Serbo-Croatian depends heavily on a phonemically derived code, while in English, most evidence presented so far suggests that phonemic codes are less often used (Coltheart, Davelaar, Jonasson, & Besner, 1977; Forster & Chambers, 1973; Frederiksen & Kroll, 1976). Katz and Feldman (1985) support this suggestion with data that directly compare Serbo-Croatian and English readers.

The present study extends the consideration of the relation between orthography and the process of printed word identification to Hebrew. The Hebrew orthography offers a unique opportunity for studying a reader's dependence on phonemic codes, because it allows manipulation of the phonological information carried by a single string of letters. Hebrew has an unusual system for representing vowels in print: small graphic symbols (dots) that are appended to the consonants, but cannot stand by themselves. The full writing system (consonants and dots) is initially taught in the first grades of elementary school, but the adult reader sees it only infrequently outside of prayer books and poetry. In all other printed material the vowel dots are omitted. This produces a situation where many (but not all) Hebrew words with the same sequence of consonant characters can be pronounced in several ways, each one a different legal Hebrew word (Figure 1). In order to pronounce the word, the reader must assign one of these alternatives to the character string on the basis of the context.

The Hebrew orthography can be considered, therefore, to represent phonemic information even more indirectly than English. While, in English, vowel
symbols are always present but may represent alternative phonemic representations, such vowel symbols are totally absent in normally printed Hebrew, and the phonemic representation of a string of letters becomes correspondingly more ambiguous. Importantly, the missing information is vowel information, so that no articulation of the remaining consonants is specified in the print; only abstract consonantal phonemic information remains. Given this lack of specificity in the phonemic realization of the word, it would seem to be likely that printed words in Hebrew map directly to more abstract morphophonological representations.

Examples of single and multiple pronounceable Hebrew consonant strings

<table>
<thead>
<tr>
<th>Hebrew words</th>
<th>sefer</th>
<th>sapar</th>
<th>sipar</th>
<th>safar</th>
<th>spor</th>
<th>supar</th>
<th>saper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phonetic representation</td>
<td>book</td>
<td>barber (he) told</td>
<td>(he) counts</td>
<td>he counted</td>
<td>count</td>
<td>was told</td>
<td>was cut</td>
</tr>
<tr>
<td>English translation</td>
<td>(he) told</td>
<td>(he) counts</td>
<td>he counted</td>
<td>count</td>
<td>was told</td>
<td>was cut</td>
<td>fell</td>
</tr>
</tbody>
</table>

Figure 1. Examples of single and multiple pronunciation Hebrew words.

The present study was designed to test this hypothesis, that is, to determine the extent to which phonemic information is relied on for word identification in Hebrew. If the relation between the directness of an orthography and phonemic coding that we have described above is true, then we should find little dependence on phonemic coding. Lexical decision in Hebrew should be less dependent on phonemic translation of the print. Nevertheless, the suggestion has been made (Navon & Shimron, 1981) that the skilled Hebrew reader uses phonemic information in general and vowel information in particular in accessing the mental lexicon, that is, that printed word identification depends on a phonemic code. Navon and Shimron base this proposal on experiments in which subjects named Hebrew words that had been printed either
with or without vowels. Naming was found to be faster for words with vowels. Furthermore, substituting a graphemically different but allophonically identical vowel for the correctly spelled one did not slow the response, that is, graphemic dissimilarity did not disrupt naming. But the authors' proposal that lexical access is dependent on a phonemic code was an extrapolation from their naming experiments; no lexical decision experiments had been run. In naming, both prelexical and postlexical factors influence the performance. On the other hand, because naming necessarily involves the use of phonemic codes, it is a task in which their possible effect on performance can be investigated. The experiments reported here use both naming and lexical decision paradigms in a complementing manner to study the use of phonemic coding of print.

In our first two experiments, subjects were presented with strings of consonants without the vowel dots. Response times to two types of strings were compared: strings that represent one and only one word uniquely (single-word strings) and strings that represent more than one word depending on the vowels (multiple-word strings) (Figure 1 gives an example of each type). As in the example, each multiple-word consonant string represents several real words, each of which would display a different set of vowels if the vowels were printed. Thus, multiple-word letter strings are phonemically and morphophonologically more ambiguous than those strings that can be related to only one lexically valid phonemic representation. An initial experiment was required in order to demonstrate that, in performing a task in which phonemic codes are used, multiple pronunciations interfere with the response. A word naming task was used for this purpose. Although a naming response can, in theory, be generated lexically, without a letter-level grapheme-to-phoneme process, it appears that the phonemic code is, in fact, characteristically used for naming printed words (Navon & Shimron, 1981). A phonemic ambiguity effect was, in fact, obtained in our naming experiment; the same stimuli were then used to assess the use of a phonemic code in lexical decision. If indeed a complete phonemic code (consonants plus vowels) is necessary for a lexical decision, response time should be delayed for multiple word strings relative to uniquely pronounceable letter strings. On the other hand, if no retardation is found, it could be because no phonemic analysis occurred, or only a partial analysis occurred that took only consonants into account. The process of word recognition was further investigated in a third experiment in which all stimuli were presented with vowel dots so that each had a unique pronunciation. The use of phonemic coding was assessed by comparing the response times to nonwords that were either phonemically or orthographically similar to real words, and to the real words that had been primed by these similar nonwords. It was expected that phonemic similarity would be less effective than orthographic similarity.

**EXPERIMENT 1**

Before multiple-word and single-word consonant strings could be compared in a lexical decision paradigm, we had to establish the validity of the manipulation. That is, we had to determine first that multiple-word strings were in fact more ambiguous than single-word strings when a complete phonemic code had to be utilized by the subject. Therefore, a naming paradigm was chosen; the requirement to pronounce the stimulus consonant string ensured that the correct vowels as well as the consonants would be coded at some point...
in the process. If multiple-word strings failed to be pronounced more slowly than single-word strings, the same comparison would be of no value in a lexical decision paradigm. On the other hand, a positive result would allow further exploration of this ambiguity effect.

Method

Subjects. Eight male and eight female undergraduate students participated as part of the requirements of an introductory psychology course. They were all native speakers of Hebrew with normal or corrected-to-normal vision, and were naive with regard to the experimental hypothesis.

Stimuli and apparatus. Three hundred words, printed as consonant strings without vowels, were presented to 15 judges who classified each as high, medium, or low frequency. All words consisted of three letters and were two syllables in length. Since some of the characters in Hebrew may be given a vowel sound in addition to their customary consonant reading, only words that are spelled with pure consonants were selected. Those words that were classified by at least 13 of the 15 judges in one of the two extreme frequency groups were considered for inclusion in the set of experimental words. From each of the two frequency groups, 12 nouns with only one legal pronunciation each and 12 words with at least three legal pronunciations each (one of which was a noun) were selected, making a total of 48 stimuli in all.

All of the stimuli were generated by a computer to appear in the center of a cathode ray tube. The size of each letter was 1 cm x 1 cm and the length of the whole word was 5 cm, subtending a visual angle of approximately 4.1 degrees.

The subject's verbal response was recorded by a Mura DX-118 microphone, which was connected to a voice key. The reaction time was measured by the computer from stimulus onset.

Procedure. The experiment took place in a semi-darkened soundproof room. Subjects sat approximately 70 cm from the screen. They were instructed to name, as fast as possible, individual words that appeared on the screen at a rate of one every two seconds. Stimulus duration was terminated by the subject's response. (There were no failures to respond within two seconds.) The verbal response given by the subject was recorded by the experimenter in order to detect reading errors and pronunciation preferences, if any. All 48 words were presented in one session that was preceded by 5 training trials.

Results

Reaction times were averaged for each subject over the 12 words in each combination of frequency (high/low) and number of pronunciations (single/multiple). The reliability of these means was assessed by calculating a coefficient of variation (the ratio of standard deviation over mean). All the coefficients were lower than 0.2, suggesting that the means were reliable estimates for the individual distributions.

Inspection of Figure 2 suggests that there were effects of both frequency and phonemic ambiguity. This was supported by an analysis of variance that
revealed that both the frequency and phonemic ambiguity factors were significant. Response times to high frequency words were faster than to low frequency words, $F(1, 15) = 48.99, \text{MSE} = 2543, p < .001$. With both high and low frequency words, the response to strings that were phonemically ambiguous was delayed relative to those strings that had only one legal pronunciation, $F(1, 15) = 31.94, \text{MSE} = 5728, p < .001$. The interaction was not significant.

![Figure 2. Naming time for single and multiple pronunciation, low and high frequency words.](image)

Analyses of the specific pronunciations produced for multiple-word items by each subject showed that all words were given a legal pronunciation. However, there was variability in the specific word that subjects chose to assign to a given consonant string. For the set of 24 multiple-word items, the range of the number of subjects giving identical responses was 5 to 15 (out of a total of 16 subjects) with a median number of 7.

Discussion

Multiple-word consonant strings were named more slowly than single-word strings. It is clear, therefore, that in naming, subjects could not ignore the multiple phonemic (or semantic) representations of the ambiguous string.
However, the results were equivocal with regard to the locus of the effect; both prelexical and postlexical explanations remained viable for the naming task. Nevertheless, the outcome of this experiment placed constraints on the interpretations of possible outcomes for a lexical decision experiment. The absence of an ambiguity effect in a lexical decision experiment could only indicate that the source of the effect in Experiment 1 was postlexical in nature and that phonemic ambiguity (and, therefore, a phonemic code) has no effect on lexical access.

**EXPERIMENT 2**

Multiple-word and single-word consonant strings without vowels were presented in a lexical decision paradigm. If multiple-word strings are recognized by means of a phonemic code, then the ambiguity in the transform from print to phonemics should delay the decision to those strings relative to single-word strings. On the other hand, if no effect of ambiguity is found, this result, together with the outcome of Experiment 1, will suggest that a phonemic transform of print does not play an important role in word recognition in Hebrew.

**Method**

**Subjects.** Eight male and eight female undergraduate students participated as part of the requirements for an introductory psychology course. They were native Hebrew speakers and were about the same age as the subjects in Experiment 1.

**Stimuli and apparatus.** The same 48 words used for naming in Experiment 1 were used for lexical decisions in this experiment: 24 high frequency and 24 low frequency words. In each frequency group, half of the consonant strings could take only one legal pronunciation, while the others could be pronounced in at least three different ways. Forty-eight nonwords were added; they were formed by permuting the order of the consonants of the real words so that the result had no possible pronunciation that would form a legal word. Since the vowels were not printed, all the nonwords could be pronounced by arbitrarily assigning vowels. All 96 stimuli were presented with a different randomization for each subject.

**Procedure.** The conditions of Experiment 1 were repeated in this experiment. In addition, the subjects were instructed to press one of two alternative microswitch buttons, according to whether the stimulus on the screen was or was not a legal Hebrew word. The dominant hand was always used for "Yes" (i.e., "word") responses and the contralateral hand for the "No" responses.

Following the instructions, ten training trials (5 words and 5 nonwords) were presented. Then, 96 test trials were given in two blocks of 48 trials each. A ready signal preceded each block. The subject started the test stimulus sequence in each block by pressing a start button that cleared the screen. The interstimulus interval was 2 sec. The interblock time interval was between 3 and 5 minutes.
Results

The reaction times for correct "Yes" (i.e., "word") responses were averaged for each subject over the twelve words in each combination of high and low frequency and single and multiple pronunciation. These averages were tested for reliability by computing a coefficient of variation. All coefficients of variation were smaller than 0.2.

Responses to high frequency words were significantly faster than responses to low frequency words, $F(1, 15) = 57.21$, $MSe = 3171$, $p < .001$. In addition, a significant interaction was found between frequency and phonemic ambiguity, $F(1, 15) = 10.37$, $MSe = 1204$, $p < .001$. Examination of the means revealed an unexpected result. Although Fisher's protected t-tests indicated that reaction times to single-word and multiple-word stimulus strings were not different for high frequency words, there were differences for low frequency words. In contrast to the delayed response to multiple-word strings that was found in Experiment 1, the lexical decisions for low frequency, multiple-word strings were faster than for low frequency, single-word strings, $t(15) = 3.18$, $p < .01$. These results are presented in Figure 3.

![Figure 3](image-url)  
Figure 3. Lexical decision time for single and multiple pronounciation low and high frequency words.
Error percentages are presented in Table 1. An analysis of variance on the percentage of errors in each group revealed that there were significantly more errors for low frequency words than for high frequency words, $F(1,15) = 14.99$, $p < .001$. No other effects were found.

Comparison of the response times in Experiments 1 and 2 revealed that it took significantly longer to name the words than to recognize them in the lexical decision task, $t(28) = 3.11$, $p < 0.004$.

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**Table 1**

Percentage of Incorrect Responses to Single and Multiple Pronunciation High and Low Frequency Words in a Lexical Decision Task.

<table>
<thead>
<tr>
<th>Pronunciation</th>
<th>Single</th>
<th>Multiple</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>7.29%</td>
<td>5.21%</td>
</tr>
<tr>
<td>Low</td>
<td>1.56%</td>
<td>1.56%</td>
</tr>
</tbody>
</table>

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**Discussion**

In contrast to the effects found for naming, lexical decision time was not slower for multiple-word strings. On the contrary, multiple-word strings were recognized even faster than single-word strings, for low frequency words (but not for high frequency words). There are two alternative explanations for these results.

The first explanation is based on the assumption that in Hebrew the phonemic code plays only a minor role in lexical access. Consequently, phonemic ambiguity should have no effect on the response time when overt naming is not required. The delayed response for multiple word strings in naming would be, then, the result of a postlexical interference such as the requirement for response selection.

This hypothesis would predict no phonemic ambiguity effects for both high and low frequency words. However, if the frequency of the letter strings is considered (by a cumulative frequency of all the possible phonological realizations of the same consonant string), the response facilitation for low frequency multiple word strings might be the result of an artifact of the procedure used to select high and low frequency word stimuli for the experiment. Frequency was determined by means of ratings obtained from judges, but the judges may have systematically underestimated the true
frequency of the multiple word consonant strings. This would have happened if the judges considered only one (probably the most frequent) meaning, of the several belonging to each string, ignoring the additional phonological realizations that were possible. Our introspections suggest that this certainly could have happened. The underestimation would affect the low frequency strings more, since the frequency added to a given string by each phonologic alternative is relatively higher. Thus, the apparent facilitation of the low frequency multiple-word strings would be accounted for as a simple frequency effect; the multiple-word strings we used may have been more frequent than the single word strings. Unfortunately there is no reliable source of word frequency data in Hebrew; therefore, this hypothesis could not be verified.

A second way of accounting for the absence of an interference effect due to phonemic ambiguity is based on the assumption that a multiple-word string activates its several different phonemic codes, which activate different entries in the lexicon simultaneously. The facilitation might be accounted for as an interaction among phonemic representations. Then, the interference effect in naming associated with phonemic ambiguity must be accounted for as the net result of a tradeoff between a process of rapid parallel lexical access and interference among the resultant phonemically coded words that compete for articulation. However, this hypothesis does not explain the interaction between the frequency and the number of phonemic realizations.

We favor the first explanation, in which a direct mapping of the print to abstract morphophonological representations is suggested. Support for this explanation is provided by other data that indicate that, when multiple phoneme codes are used for lexical access, the result is an inhibition, rather than a facilitation, of word recognition. The data are from experiments in the Serbo-Croatian language. As we stated above, printed words in Serbo-Croatian have unique pronunciations. However, printed material can be produced in either of two different alphabets, the Cyrillic and the Roman. Although the two alphabets consist of distinct graphemes, for the most part, there are some graphemes common to both alphabets, and some of these have different pronunciations in the two alphabets. That is, there are some letters that look identical but sound different. A string that is made up of these phonemically ambiguous letters will have two pronunciations, one in each alphabet, either or both of which may be a real word. Both alphabets are taught to all children in elementary school and native speakers typically become facile at reading in either. Experiments by Feldman and Turvey (1982), and by Lukatela, Popadić, Ognejenović, and Turvey (1980) have demonstrated that subjects are slower in recognizing phonemically ambiguous words in lexical decision and naming tasks and that the inhibition is due to the ambiguity of the phonemics and not to the duality of meaning. In contrast, in English, it has been shown that multiple meanings speed lexical decisions rather than inhibit them (Forster & Bednall, 1973; Jastrzembski & Skanners, 1975). Therefore, in the present experiment, it seems unlikely that the phonemic ambiguity of the Hebrew multiple-word strings would be the source of facilitation in lexical decision, a result that would be inconsistent with the findings in Serbo-Croatian. Rather, consistent with the findings for English, the facilitating effect on multiple-word strings is more likely to be due to causes unrelated to phonemic coding.
EXPERIMENT 3

Although the evidence in Experiment 2 suggests that full phonemic coding does not precede lexical access, the results were not unequivocal. Therefore, a third experiment was run. A lexical decision priming paradigm was used in which all stimuli, both targets and primes, were printed with full notation, that is, including vowels. The critical target words were preceded by nonwords that were either orthographically similar to the target or were phonemically similar. The two members of an orthographically similar prime-target pair were spelled with identical consonants but with different vowels, so that the pronunciation of the prime resulted in a nonword. A phonemically similar pair contained members that were pronounced identically but were spelled differently, by using one different, but allophonic, consonant between the two strings. Examples are given in Figure 4.

Examples of phonetic and orthographic priming

<table>
<thead>
<tr>
<th>FREQUENCY</th>
<th>TYPE OF PRIMING</th>
<th>PRIMES (nonwords)</th>
<th>TARGETS (words)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ORTHOGRAPHIC</td>
<td>STIMULUS</td>
<td>PHONEME</td>
</tr>
<tr>
<td>HIGH</td>
<td></td>
<td>א&quot;מ</td>
<td>aven</td>
</tr>
<tr>
<td></td>
<td>PHONETIC</td>
<td>קסף</td>
<td>kesef</td>
</tr>
<tr>
<td>LOW</td>
<td>ORTHOGRAPHIC</td>
<td>_nek١</td>
<td>nekiv</td>
</tr>
<tr>
<td></td>
<td>PHONETIC</td>
<td>עמא</td>
<td>atav</td>
</tr>
</tbody>
</table>

Figure 4. Examples of orthographically and phonemically similar nonwords.

The implications of this manipulation are straightforward: If one type of priming facilitates and the other does not, the dominant code type is the one that is important for word recognition.

A second effect is to be expected, one that does not involve priming but concerns nonwords alone. The critical (similar) nonwords, due to their
construction, either look like real words (because of their consonant pattern) but do not sound like real words (because of their vowel pattern) or, conversely, sound like real words but do not look like them. Therefore, correct responses to these nonwords should be delayed if a search of the lexicon discovers real words that are similar. Again, the implication is clear: Either phonemically similar or orthographically similar nonwords will be slower, whichever is closer to the primary lexical code.

Method

Subjects. Eight male and eight female students who had not participated in any of the previous experiments took part in this experiment as a requirement of an introductory psychology course.

Stimuli and design. The stimuli were 48 words and 48 nonwords, all printed with the vowel dots, giving each stimulus a unique pronunciation. Twenty-four high frequency and 24 low frequency words were selected from the 300 three-consonant words as described in Experiment 1. Twelve out of the 24 words in each frequency group were selected to be targets to priming and preceded by a trial in which a nonword was presented. Twelve out of these 24 nonword primes (six for each word frequency group) were designed to produce a primarily phonemic facilitation in recognizing the following words by being identical homophones. The substitution of one letter with an allophone made them orthographically nonwords (Figure 4). The other 12 nonword primes (six in each word frequency category) had consonant strings identical to their following words, but different vowel dots made them sound like nonwords. They were expected to have a primarily orthographic priming effect (Figure 4). The other 24 words were not specifically primed.

The 24 nonwords that were not used for priming (nonsimilar nonwords), were strings of 3 consonant characters plus vowels that were obtained by recombining the consonant characters in the 24 unprimed words. Twelve additional nonwords were presented but were not considered for analysis: These nonwords were similar to words (six orthographically and six phonemically), but they were not followed by any real word counterparts. These 12 words were presented in order to discourage the subjects from predicting the occurrence of a word on the trial following a nonword that was similar to a real word. Different quasi-randomizations were used for each subject. The only constraint on the randomization was to keep together the pairs of priming nonwords and priming words. All stimuli were generated on a CRT in the same way as for Experiments 1 and 2.

Procedure. The procedure was similar to that followed in Experiment 2. The subjects were instructed to press the appropriate button as fast as possible. They were told that both the spelling and the sound of a stimulus counted for the decision. Ten training trials (5 words and 5 nonwords) preceded the first experimental trial block.

Results

Both reaction times and error percentages were averaged over the words within conditions for each subject. Errors were few (from zero to a maximum
of three errors per condition). Analyses of variance on errors produced no significant results.

Inspection of Figure 5 shows that for reaction times, both graphemic and phonemic similarity interfered with correct nonword responses. However, graphemic similarity delayed the correct "Mn" responses significantly more than the phonemical similarity. This suggestion was supported by a one-way analysis of variance on the correct "NO" responses, which revealed that nonwords that were not similar to words were the easiest for the subject to reject as words. Response time was fastest for the dissimilar nonwords and longest for those that were similar graphemically, \( F(2,30) = 9.87, MSe = 3421, p < 0.001 \). Two-way analysis of variance on the correct responses for only those critical nonwords that were similar to words revealed that it took significantly longer to reject the nonwords that were graphemically similar to words than the nonwords whose similarity was mainly phonemic, \( F(1,15) = 5.45, MSe = 18136, p < .04 \). Also, it was found that nonwords that were similar to high frequency words were rejected faster than those nonwords that were similar to low frequency words, \( F(1,15) = 11.44, MSe = 2632, p < .004 \). There was no significant interaction.

Words that were preceded by similar nonwords were responded to faster than words that were preceded by unrelated nonwords or by unrelated words (Figure 6). However, the facilitation effect of both graphemic and phonemic similarity did not differ significantly. An analysis of Frequency (High/Low) by Priming (Primed/Unprimed) for reaction times on correct word responses revealed that primed words were, in fact, responded to faster than unprimed words, \( F(1,15) = 58.7, MSe = 6057, p < .001 \). Also the reaction times to high frequency words were faster than to low frequency words, \( F(1,15) = 27.72, MSe = 5613, p < .001 \). A second analysis of variance of Frequency (High/Low) by Priming Mode (Graphemic/Phonemic) on the reaction times to primed words revealed that even within the group of primed words, the high frequency words were responded to faster than the low frequency words, \( F(1,15) = 8.06, MSe = 9630, p < .01 \). The reaction times to the graphemically primed words appeared to be faster than to phonemically primed words, but this difference failed to reach statistical significance. Also, the Frequency and Priming Mode factors did not interact significantly.

The response time to the unprimed words and the nonsimilar nonwords in Experiment 3 was compared with the response time to words with single pronunciation and nonwords in Experiment 2. Two factors analysis of variance revealed that the response times were faster in Experiment 2, \( F(1,30) = 41.95, MSe = 24292, p < 0.0001 \). Also, the response time to words was faster than to nonwords in Experiment 3, but slower in Experiment 2. This interaction was supported by the analysis of variance, \( F(1,30) = 11.07, MSe = 4430, p < 0.002 \).

Discussion

Those nonwords that were misspelled but phonemically similar to words were rejected faster than those that were similar in print but differently pronounced. In addition, the responses to both of these groups of nonwords were delayed relative to responses to regular nonwords (i.e., nonwords that neither look nor sound like real words).
Figure 5. The reaction time to nonwords that were similar or nonsimilar to real words in a lexical decision task.

Figure 6. The reaction time to primed and unprimed words in a lexical decision task.
Other investigators have also demonstrated that certain classes of nonwords are harder to reject as real words. For example, it has been reported that nonlegal nonwords were responded to faster than legal nonwords (Stanners & Forbach, 1973). In a different study, Coltheart et al. (1977) assigned nonwords an index \( N \), where \( N \) was the number of different English words that could be produced by changing just one of the letters in the string to another letter, preserving letter positions. Nonwords with higher \( N \)'s were responded to slower than nonwords with lower \( N \)'s. These results suggest that the more similar a nonword is to a real word, the longer is the lexical decision time required to reject it. It seems, therefore, that in the present study the orthographically similar nonwords were associated with the real words more closely than were the phonemically similar nonwords. Of course, both groups of similar nonwords shared both phonemic and orthographic information with real words. It was reported, however, that the rejection of pseudohomophones is interfered with by their visual rather than phonemic similarity to words (Martin, 1982).

A correct \( \text{"No"} \) response to the orthographically similar nonwords must have been based on reading the vowel dots in addition to the consonants. In contrast, correct rejection of the phonemically similar nonwords could be made by considering only the consonantal letters alone. Since the adult Hebrew reader does not habitually read the vowels, it could be argued that this might, by itself, explain the precedence given to consonants and, thus, the difference observed between the two nonword categories. This explanation assumes that identification of printed words in Hebrew is primarily based on the consonant configuration that contains only partial information about a word's phonemics. Thus, this implication is in complete agreement with the hypothesis raised in this study, that the process of printed word recognition in Hebrew is based mainly on the orthographic information provided by the consonant letters.

The interference with correct \( \text{"No"} \) responses found in this study can be explained within the context of the logogen theory suggested initially by Morton (1969, 1970), and later expanded to explain nonword responses by Coltheart et al. (1977). According to this model, lexical memory includes a set of evidence-collecting devices—the logogens. These logogens serve as an interface between the sensory system and the cognitive lexical memory. Each word in memory has its own logogen. Logogens are activated by stimuli that are physically similar to the words to which the specific logogens are related. There is a positive correlation between the amount of similarity and the level of the logogen excitation. Logogens have thresholds that are inversely related to word frequency. Whenever a logogen is excited beyond its threshold, the access to the word in the cognitive lexicon is achieved and the \( \text{"Yes"} \) response is generated. However, if no logogen was excited beyond its threshold within a given time limit, a \( \text{"No"} \) response is generated. This time limit is dynamically adjusted up and down during processing. Stimuli that are similar to words represented in the lexicon tend to excite the logogen system more rapidly. As a consequence, the probability that the stimulus is indeed a word is high, and the time limit for a \( \text{"No"} \) response is increased. Within this conceptual frame, the nonwords in this experiment that were similar in print to real words would have excited the logogen system more rapidly, and to a greater extent than those whose similarity was mainly phonemical. We may
conclude then that the orthographic analysis of the stimuli was completed first, while the phonemic analysis was only secondary.

Words are responded to faster if they are repeated within an experiment (Scarborough, Cortese, & Scarborough, 1977), or when preceded by semantic associates (Meyer, Schvaneveldt, & Ruddy, 1975). This effect is explained by the logogen theory as a "temporal summation" effect: When a logogen is fired, its threshold is reduced, and returns to baseline very slowly (Morton, 1979). Although not specified by Morton, this effect may not need to depend on above threshold preactivation of the logogen. Even limited arousal of a logogen might increase its baseline arousal level for a limited time period. Within this time period, less analysis would be required to fire this logogen, therefore faster response times would be measured (compare with the graded postsynaptic potentials and temporal summation of neurons). The priority of the letter analysis in the word identification process that was indicated by the correct "No" responses to nonwords suggests that real words that immediately follow orthographically similar nonwords should be responded to faster than those words that are preceded by the phonemically similar nonwords. However, the results failed to support this prediction. The facilitation effect of both the phonemically and the orthographically similar nonwords on the following real words was significant, but the amount of priming was not significantly different for the two conditions. One way to explain this incongruity between the similarity effects on "Yes" and "No" responses would be to assume that in the process of printed stimulus analysis, lexical activation of related items occurs. In this experiment, although the correct "No" response was generated by the logogen system in a nonword trial, the lexical memory could have been accessed either by a post decision analysis or through a verification process involved in the decision process itself (Becker, 1979; Becker & Killion, 1977). If the lexical entry of a real word that was suggested by the nonword was indeed accessed, the priming could be explained by a feedback from the cognitive system to the logogens in the same way this model would explain contextual priming effects (Besner & Swan, 1982). In this account the similarity of the nonwords would not have affected the thresholds of the real words directly, but rather, indirectly through an abstract, conceptual mediator, which once accessed, had lost the orthographic or phonemic specificity.

GENERAL DISCUSSION

The question investigated in this study was to what extent identification of printed words involves the use of phonemic codes on the letters. The results suggested that, in Hebrew, printed word recognition is not primarily mediated by a phonemic code. Phonemic ambiguity, which did interfere with the naming of words, did not interfere with their silent identification as words (i.e., in lexical decisions). Furthermore, subjects found it more difficult to reject a nonword that looked like a real word but sounded differently, than to reject a nonword that sounded like a real word but was orthographically different; orthographic information appeared to fit more closely to the code used by the reader for word identification than did phonemic information. The data suggest that, at least in Hebrew, a direct mapping exists from the print to a representation in the lexicon more abstract than the phoneme. These representations may be morphophonological in nature, consisting, for example, of the consonantal root from which the several inflectionally and derivationa-
ly related versions are eventually formed. However, there were only a few orthographically similar nonwords that were mistaken for words, indicating that phonemic information (as vowel information) must also have been used at some point. An alternative explanation is that the incorrect vowel dots altered the orthographic representation of the stimulus. This seems implausible, because a reader's lexical representations are unlikely to include orthographically represented vowels (Navon & Shimron, 1981). Therefore, the printed vowel information would almost certainly be used as cues for articulation by producing explicit phonemic rather than orthographic information. This phonemic encoding may have been used to disambiguate the orthographically similar nonwords; such a "verification" process is described below.

Several studies have suggested that the use of a phonemic code is optional and task dependent. Subjects will employ this strategy depending on the advantages and the disadvantages of its use in a particular task (Coltheart, 1978; Davelaar, Coltheart, Besner, & Jonasson, 1978; Stanovich & Bauer, 1978). Our results support this hypothesis. As a rule, the response times to comparable stimulus groups were longer in Experiment 3 where the vowel dots were added to the consonant strings, than in Experiment 2 where the vowel dots were not included. The response time to unprimed words in Experiment 3 was longer than the response time to the words in Experiment 2. Similarly, the response time to regular nonwords in Experiment 3 was longer than the response time to nonwords in Experiment 2. The presence of the additional phonemic information (i.e., inclusion of vowel dots) in Experiment 3 was not ignored by the subjects, who probably used it for further stimulus verification. The need for phonemic verification may have been increased in Experiment 3 by the presence of the orthographically similar words. In a previous study (Pentin & Carmon, Note 1), we have found that when words were presented with vowel dots, the nature of the nonwords determined the amount of phonemic verification. High and low frequency words with similar consonants were not responded to differently when the nonwords were meaningless permutations of the same letters. In contrast, the expected frequency effect was found when the nonwords were the same consonants with different vowel dots. We suggest that, in Hebrew, phonemic translation of the print is normally not necessary for word identification, and is employed only when the phonemic code is the single discriminative factor between words and nonwords.

The nature of the code used by subjects for word recognition does not depend only on the nature of the task. The complexity of the mapping rules from the orthographic to phonemic sets is probably a more basic and important factor. It has been demonstrated that in languages in which the mapping function is a simple isomorphism, such as in Serbo-Croatian, printed word recognition usually includes letter to phoneme transformation (Feldman & Turvey, in press). The language factor probably explains also the longer response times found in this study for lexical decisions (in Experiment 2) relative to naming. Forster and Chambers (1973) reported longer response times for lexical decisions than for naming in English. This relationship was replicated in Serbo-Croatian, but not in English (Katz & Feldman, in press). In the latter study, it was reported that semantic priming facilitates lexical decisions in both languages, whereas naming is facilitated only in English. It was suggested that in the shallow orthography of Serbo-Croatian, naming might be a direct mapping of phonemic information extracted from the script, to the articulatory system. In Hebrew, in contrast, print does not normally
provide sufficient phonemic information, and therefore, naming must be mediated by the internal lexicon. This additional step slows down naming relative to lexical decision.

The mediation of the internal lexicon probably explains the similar priming effects of the orthographically and phonemically similar nonwords. This mediation suggests that the lexicon had been accessed by the nonwords that were similar to words. Since correct "No" responses were given to those nonwords, this lexical access could have happened either before a final verification was performed, or following the correct "No" response. Both alternatives have interesting implications for models of word recognition and reading. Lexical access preceding final verification implies that lexical access does not automatically elicit a "Yes" response in a lexical decision task. On the other hand, access to the internal lexicon following the response would imply that, for the literate adult, strings of letters trigger an automatic process of word recognition that is terminated only when a complete exhaustive linguistic analysis is achieved. Further investigation is necessary to determine whether either of the two alternatives, or both, are valid.

REFERENCE NOTE


REFERENCES


