Reading Consonants and Guessing Vowels: Visual Word Recognition in Hebrew Orthography*

Ram Frost† and Shlomo Bentin†

For many years studies in the English language have dominated experimental research in visual word recognition. This state of affairs cannot be accounted for by considering merely geographic reasons. Rather, it was partly due to an underlying belief that English was sufficient because reading processes (as well as other cognitive processes) are universal. In recent years, however, studies in orthographies other than English have become more and more prevalent. These studies have the common view that reading processes cannot be explained without considering the reader's linguistic environment. Moreover, it is assumed that reading strategies in one orthography can be understood better when other orthographies provide additional points of reference. It is in this context that recent research in reading Hebrew should be evaluated. In the present chapter we describe the specific characteristics of Hebrew orthography and discuss their origin with regard to the complex morphology of the Hebrew language. We further examine their possible effects on the reading strategies adopted by beginning and skilled readers. Finally, we discuss the processing of morphologic information conveyed by Hebrew print, a particularly interesting contrast to other writing systems that have been studied.

CHARACTERISTICS OF THE HEBREW ORTHOGRAPHY

The orthography of the Hebrew language should be described in reference to its very complex productive morphology (see Katz & Frost, this volume). In Hebrew, as in other Semitic languages, all verbs and the vast majority of nouns and adjectives are comprised of roots which are usually formed of three (sometimes four) consonants.

The three-consonant roots are embedded in pre-existing morphophonological word patterns to form specific words. Phonological patterns can be either a sequence of vowels or a sequence consisting of both vowels and consonants. Thus, in general, Hebrew words can be decomposed into two abstract morphemes, the root, and the phonological pattern. Roots and phonological patterns are abstract structures and only their joint combination (after the application of phonological and phonetic rules) forms specific words. Although these morphemes carry some semantic and morpho-syntactic information, their meaning is often obscure and changes for each root-pattern combination (see Berman, 1980). This is because there are no unequivocal rules for combining roots and phonological patterns to produce specific word meanings. For example, the word KATAVA ("a newspaper article") is composed of the root KTV, and the phonological pattern -A-A-A (the lines indicate the position of the root consonants). The root KTV alludes to anything related to the concept of writing, whereas the phonological pattern A-A-A is often (but not always) used to form nouns that are usually the product of the action specified by the root. It is the combination of both root and word pattern that forms the word meaning "article". Other phonological word patterns may combine with the same root to form different words with different meanings that can be closely or very remotely related to writing. For example, the word KATAV ("press correspondent") is formed by combining the root KTV with the phonologic pattern -A-A-. The phonological pattern -A-A- carries the morpho-syntactic information that the word is a noun which signifies a profession. But
Figure 1. Phonologic ambiguity in unpointed Hebrew print.

The root \( \text{דבר} \)

\( \text{דר} \) \( \text{דר} \) \( \text{דר} \) \( \text{דר} \) \( \text{דר} \) \( \text{דר} \)

/davar/ /dabei/ /dibari/ /dabari/ /deveri/
(thing) (speak!) (he spoke) (was spoken) (pestilence)

/doveri/ (speaker, he speaks)

Because of the productive characteristic of Hebrew morphology, Hebrew orthography was designed to convey to the reader primarily the root information (see Katz & Frost, this volume). Hence, the letters in Hebrew represent mainly consonants. The vowels are depicted by diacritical marks (points and dashes) presented beneath (sometimes above) the letters. Although the diacritical marks carry mainly vowel information, they also differentiate in some instances between fricative and stop variants of consonants. In modern Hebrew, we have lost most of the phonetic differentiation between fricative and stop pronunciations, but it is still kept for 3 consonants, in which the letter indicates two different phonetic realizations of these phonemes: /b/\( \rightarrow \) [b] or [v], /p/\( \rightarrow \) [p] or [f], and /k/\( \rightarrow \) [k] or [x]. In these cases a point is inserted inside the letter to indicate the stop pronunciation. Thus the presentation of vowels reduces considerably several aspects of phonemic ambiguity. The diacritical marks, however, are omitted from most reading material, and can be found only in poetry, children’s literature, and religious scripts. Although some of the vowels can also be conveyed by letters, these letters are not regularly used, and are considered optional. Thus the most salient characteristic of the Hebrew orthography is that it presents the reader with only partial phonological information. However, incomplete phonologic information is only one specificity of the Hebrew orthography. Because the same root may be combined with different word patterns, frequently the vowel-sequence is the only difference between several words. Therefore, when the vowel marks are omitted, the same string of letters sometimes denotes up to seven or eight different words. Consequently the Hebrew reader is normally exposed to phonological as well as semantic ambiguity. An illustration of Hebrew unpointed and pointed print is presented in Figure 1.

The root \( \text{דבר} \)

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/davar/ /dabei/ /dibari/ /dabari/ /deveri/
(thing) (speak!) (he spoke) (was spoken) (pestilence)

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The Figure describes the possible reading of one consonant cluster. The unpointed letter string \( \text{דבר} \) has five meaningful possible readings. The letter \( \text{ד} \) can be read either as [v] or [b] which are distinguished by a dot that appears within the letter, but only in pointed print. The triconsonantal root \( \text{דבר} \) can, thus, be read as /dvr/ or /dbr/ and forms 3 clusters of words: Three words inflected from the root /dbr/ which signifies the action of speaking, and two words /davar/ and /dever/ which share the same consonants, but originated historically from different languages, and therefore do not share any semantic features (the former meaning “a thing” while the latter means “pestilence”). An example of a phonologic pattern which is conveyed by letters in addition to diacritical marks underneath the consonants can be seen in the word /dover/. Note that in the present tense of the root /dbr/ the pronunciation of the middle phoneme /b/ changes into a /v/. These interchanges between fricative and stop
pronunciations of consonants are very common in Hebrew. For /dover/ the phoneme /o/ is conveyed by the letter 1. In its unpointed form, this letter can represent the phoneme /o/ as well.

The introduction of vowel marks in printed Hebrew

For the above reasons, Hebrew orthography was designed to provide the reader with the abstract root information, regardless of the possible words that the letter string might represent. Thus, the unpointed orthography served the purpose of denoting in print the optimal amount of phonologic information. The gain in omitting the vowels from the print was multiple: First, the set of letters in the alphabet was smaller—Hebrew has only 22 letters, and the written words were shorter. Second, the presentation of consonants alone made the abstract root more salient. Indeed, the original Hebrew writing system was unpointed. It remained unpointed as long as Hebrew was a living language, that is until the second century.

It was only between the second and the tenth century that the vowel marks were introduced into Hebrew orthography (see Morag, 1972). Since after the second century most of the Jewish nation was dispersed in Europe, Asia, and Africa, they no longer spoke Hebrew as their native language. For the fear that the correct pronunciation of the Hebrew words in the holy scriptures might be forgotten, the vowel marks were introduced. The point of interest in this historical analysis is that the vowel marks were not necessary when Hebrew was a living spoken language. Their function of denoting the specific pronunciation of the letter string might become a necessity only when Hebrew ceased to be a naturally spoken language. It is worth noting that the vowel marks were used only for writing holy scriptures or poetry. This is because it is only for poetry and religious scripts that the exact phonemic notation is indeed crucial. Nevertheless, as will become evident in the next section, the importance of vowel marks for both beginning and skilled readers is incontestable.

The use of vowel marks by the beginning reader

Vowel marks aid phonologic recoding. Aside from poetry and religious texts, most children's literature in Hebrew is pointed. Traditionally, most schools in Israel have adopted methods of teaching reading which involve the use of vowel marks at the initial stages of reading acquisition. The purpose of this method is two-fold. First, the vowels convey the unequivocal phonemic structure of the printed word to the beginning reader. It is well established today that beginning readers recognize and name printed words through a process of phonological mediation (e.g., Calfee, Chapman, & Venezky, 1972; Conrad, 1972; Shankweiler & Liberman, 1976). Moreover, decoding skills were shown to be a developmental prerequisite for efficient reading for meaning (e.g., Perfetti & Hogaboam, 1975). Phonemic recoding based on grapheme-to-phoneme conversion rules is very simple in pointed Hebrew. In fact, in its pointed form, Hebrew orthography is almost as shallow as the Serbo-Croatian orthography (Katz & Frost, 1992) and allows a simple use of prelexical phonologic processing. Without the vowel marks the beginning reader in Hebrew would have to rely on the holistic identification of consonant clusters and their correspondence to spoken words, which as mentioned above is extremely ambiguous.

Vowel marks affect phonologic awareness. A second gain in teaching children to read with vowel marks is their beneficial effect on the development of phonological awareness. Phonological awareness is the ability to consciously recognize the internal phonemic structure of spoken words (Bentin, this volume). Several authors reported that the ability to manipulate phonemic segments consciously, develops only around the first grade in elementary school (e.g., Liberman, Shankweiler, Fisher, & Carter, 1974), and has been positively correlated with reading ability (e.g., Bertelson, 1986; Bradley & Briant, 1983; 1985; Liberman & Shankweiler, 1985). This correlation was used to develop methods for predicting in kindergarten, how efficiently would the children acquire the reading skills in school (Lundberg, Olofsson, & Wall, 1980; Mann, 1984). Recently, the importance of phonological awareness for reading was demonstrated also in Hebrew (Bentin & Leshem, in press). In that study, the authors found that children who scored low on a phonemic awareness battery administered in kindergarten scored also low on a reading test in school. However, if those children were trained in kindergarten and improved their segmentation skills, they reached the school standards and read as well as children who had scored highly on the initial tests of phonological awareness.

The relationship between phonological awareness and reading is not, however, unidirectional. Several studies have suggested that, in the absence of reading instruction, the
ability to isolate and manipulate single phonemes in coarticulated syllables is obstructed (e.g., Bertelson & de Gelder, 1990). Apparently, by being exposed to the alphabetic principle, children become aware that letters are usually mapped into single phonemes rather than into coarticulated phonological units. The emergence of this revelation should be facilitated when the relationship between letters and phonemes is simple and isomorphic (as in a shallow orthography) than when it is complex or partial (as in a deep orthography). The addition of the vowel marks to the consonants changes the Hebrew orthography from being deep to being almost as shallow as Serbo-Croatian or Italian. Therefore, by using the pointed print, teachers help triggering phonemic awareness that is essential for efficient reading acquisition.

The processing of consonants and vowel marks by the skilled reader

A question of great interest in the study of word recognition in Hebrew is how vowel marks are processed by the skilled reader. From the beginning of the third grade children are gradually exposed to unpointed print and by the sixth grade they encounter unpointed print almost exclusively. What is, then, the possible purpose of vowel marks for the skilled reader? How are they processed in print? This question is of special interest because it is often assumed that mature readers rely on fast visual-orthographic cues rather than on phonologic recoding in word recognition (see McCusker, Hillinger, & Bias, 1981, for a review).

Skilled readers cannot disregard vowel information in print

Navon and Shimron (1981) were the first to examine the use of vowel marks by skilled readers in Hebrew print. Interested to see whether readers can disregard the vowel marks while making lexical decisions, they presented undergraduate subjects with pointed letter strings, and instructed them to ignore the vowel marks while making word/nonword discriminations. Their results showed that positive decisions were slowed when the consonants formed a legal word while the marks underneath the letters suggested an incorrect vowel configuration. Consequently, Navon and Shimron (1981) concluded that although the Hebrew skilled reader does not need the vowel marks for fast lexical decisions he or she cannot ignore them even when instructed to do so (see also Navon & Shimron, 1984).

One point of interest in Navon & Shimron's study relates to the recognition of the correct vowel marks in Hebrew. Although modern Hebrew differentiates only between five vowels (/a/, /e/, /i/, /o/, /u/) it has more than five vowel marks. When the vowel marks were introduced into Hebrew between the second and the tenth century, the vocalization system that became the most influential originated from the Tiberias region. This system had two notations for /a/ (א-) and two notations for /e/ (י, -). These notations probably reflected a Hebrew dialect that was spoken in the northern part of the country and had seven rather than five vowels. Although this dialect had become extinct, the printed notations for these vowels are still used in modern Hebrew and used consistently according to orthographic rules (Morag, 1972). Navon & Shimron's results demonstrated that the Hebrew reader is not sensitive to interchanges in the printed forms of the two vowel marks representing /a/ or the two vowel marks representing /e/, as long as the correct phonemic structure of the word is maintained. This is of special interest because similar ambiguity exists with current Hebrew consonants. Hebrew has two letters representing each of the phonemes /t/, /k/, and /kh/. Similar to the vowels, these letters also reflect a historical distinction between phonemes, a distinction without phonetic reality in modern Hebrew. Nevertheless, in contrast to the insensitivity of the reader to the alternative forms of the vowel marks, the skilled reader makes very few errors in lexical decision when the letters representing these consonants are interchanged. This probably reflects the relative importance given by the skilled reader to the consonants as opposed to the vowel marks.

The inability of Hebrew readers to disregard vowel information was further examined in a study that employed the repetition priming paradigm (Bentin, 1989). In this study subjects were required to make lexical decisions to words and nonwords that were either pointed or unpointed. Orthographic, phonemic, and identity repetitions were examined at lags 0 and 15. Orthographic repetition consisted of a second presentation of the consonants but with different vowel marks. Phonemic repetition consisted of repeating the phonemes but with different letters (Hebrew has several pairs of letters that denote the same phoneme). The results showed
differential effects of phonemic and orthographic repetition for pointed and unpointed print. For unpointed print, all three forms of repetition affected lexical decisions at lag 0, whereas at lag 15 only identity repetition was effective. With pointed print, on the other hand, phonemic repetition had a significant effect at lag 15, but orthographic repetition did not. These results suggest that the vowel marks indeed attracted subjects' attention and induced phonologic coding of the printed words. Because the same phonemic cluster appeared at the second presentation, it was recognized faster even though the orthographic spelling referred to a different meaning. When the vowels were not presented to the reader, he or she was encouraged to access the lexicon through a visual-orthographic code, and the effects of phonemic repetition disappeared.

**Naming unpointed print involves postlexical phonology**

Although the vowels convey to the reader unequivocally the phonemic structure of a printed word, for many words the vowel marks are not essential for locating a specific lexical entry. For these words the consonant structure is sufficient for specifying a unique word. This is because in such cases, only one phonologic pattern can be assigned to the letter string to create a meaningful word. But even considering the prevalence of phonologic ambiguity in Hebrew, the skilled reader does not need the vowel marks for fast reading. A comparison of lexical decision time in the deep unpointed Hebrew orthography and in the very shallow Serbo-Croatian orthography revealed similar, almost identical, performance (Frost, Katz, & Bentin, 1987). Being exposed to unpointed print almost exclusively, the skilled reader in Hebrew has developed reading strategies that allow him to generate the missing vowel information in the print using the lexical route following visual lexical access. This hypothesis was confirmed by a cross-language study that compared naming strategies in deep and shallow orthographies (Frost et al., 1987). In this study lexical decisions and naming performance were examined in unpointed Hebrew, in English, and in Serbo-Croatian. The results showed that, in Hebrew, the lexical status of the word (being a high-frequency word, a low-frequency word, or a nonword) had similar effects on naming and on lexical decision, suggesting that pronunciation was achieved by an addressed routine in which the whole word phonology is retrieved from lexical memory. The lexical status of the word had smaller effects on naming in English and even smaller effect on naming in Serbo-Croatian. Similar results were obtained in a second experiment that showed stronger semantic priming effects on naming in Hebrew relative to English and Serbo-Croatian, again suggesting stronger involvement of the lexicon in naming unpointed words.

**Lexical decisions in unpointed print are based on fast orthographic recognition**

The use of the lexical route in processing Hebrew print was also demonstrated by Koriat (1984), who examined lexical decision latencies for pointed and unpointed letter strings. In his study, Koriat used Hebrew words that had only one meaningful pronunciation in their pointed form, and found almost identical lexical decision latencies for pointed and unpointed words. Moreover, the presentation of vowel marks had similar effects on words of different length. Koriat has therefore concluded that lexical access in Hebrew is probably visual and direct, not involving phonologic mediation. In a subsequent study, however, Koriat (1985) found that the presentation of vowel marks had some beneficial effect on lexical decisions. The advantage of pointed print was larger for low-frequency words than for high-frequency words, suggesting that the use of prelexical phonology is more prevalent for infrequent words. To summarize Koriat's work, it appears that despite his initial conclusions, his data indicate that the presence of vowel marks affects visual word recognition. This evidence, however, was inconclusive.

Additional and more convincing evidence suggesting that lexical decisions in Hebrew do not involve deep phonologic processing of the printed word, emerges from studies that employed words with two meaningful pronunciations (Bentin, Bargai, & Katz, 1984; Bentin & Frost, 1987). Bentin et al. (1984) examined naming and lexical decision for unpointed consonantal strings. Some of these strings could be read as two words whereas some could only be read as one word only. The results demonstrated that phonologic ambiguity affected naming but not lexical decision performance: Naming phonologically ambiguous strings was slower than naming unambiguous ones. In contrast, phonologically ambiguous letter strings were recognized as fast as letter strings with only one meaningful pronunciation. These results suggested that, although the reader of Hebrew is indeed sensitive to the phonologic
structure of the orthographic string when naming is required, lexical decisions are based on a fast familiarity judgment of the consonantal cluster and do not require a detailed phonological analysis of the printed word.

These conclusions were further supported by Bentin and Frost (1987). In this study subjects were presented with phonemically and semantically ambiguous consonantal strings. Each of the ambiguous strings could have been read either as a high-frequency word or as a low-frequency word, depending on the vowel configuration which was assigned to it. Lexical decision time for the unpointed ambiguous consonantal string was compared to lexical decision time for the unequivocal pointed printed forms of the high- or the low-frequency phonological alternatives. The results showed that lexical decisions for the unpointed ambiguous strings were faster than lexical decisions for either of their pointed (and therefore disambiguated) alternatives; explicit presentation of vowel marks did not necessarily accelerate lexical decision time. This result suggests that lexical decisions for Hebrew unpointed words may occur prior to the process of phonological disambiguation at least when the letter string represents two different words. In this case, the decisions are probably based on the printed word's orthographic familiarity (cf. Balota & Chumbley, 1984; Chumbley & Balota, 1984). On the basis of those studies we suggest that lexical decisions in Hebrew involve neither a prelexical nor a postlexical phonologic code. They are probably based upon the abstract linguistic representation that is common to several phonologic and semantic alternatives. Thus, in addition to a phonologic lexicon the Hebrew reader probably develops an “interface” lexical system that is based on consonantal strings common to several words. Whether the entries in this interface lexicon are orthographic (letters) or phonologic (phonemes that represent the consonants) in nature is hard to determine. Nevertheless, lexical processing occurs, at a first phase, at this morphophonological level. The reader accesses the abstract string and recognizes it as a valid morphologic structure. Lexical decisions are usually reached at this early stage and do not necessarily involve further phonological processing. This possibility is depicted in Figure 2.

Another set of experiments recently completed in our laboratory (Frost, in press) provides important insight regarding the use of vowel marks by the skilled reader. In this study subjects were presented with consonantal strings which were followed by vowel marks appearing at different stimulus onset asynchronies (SOA). The vowel marks were superimposed on the consonants at SOAs ranging from 0 ms...
(simultaneous presentation) to 300 ms from the onset of consonant presentation. In one condition the letter strings represented only one meaningful word, and in another condition the letter strings could represent two meaningful words. Subjects were required either to make lexical decisions or to name the words and nonwords on the computer screen as fast as possible. The aim of this manipulation was to examine whether subjects would be inclined to delay their decisions until the presentation of the vowel marks. The results showed similar decision times for simultaneous presentation of vowel marks and for their very late presentation (300 ms SOA). Thus, lexical decisions were only slightly affected by the delayed presentation of vowels. The effect was especially conspicuous with ambiguous letter strings. These results support the conclusions put forward by Bentin and Frost (1987), suggesting that lexical decisions in Hebrew are based on the recognition of the abstract root or orthographic cluster and do not involve access to a specific word in the phonologic lexicon.

In contrast to lexical decision, a very different strategy was revealed with lagged presentation of vowels in the naming task: the delayed presentation of the vowels delayed naming latencies, and the effects of SOA on RTs were twice as large as the effects found for lexical decisions. Thus, although the phonologic structure of the unambiguous words could be unequivocally retrieved from the lexicon following visual access (postlexical phonology), subjects were more inclined to wait for the vowels to appear in the naming task. Obviously, the longest delays occurred when the words were phonologically ambiguous. Because the correct pronunciation of these words was unequivocally determined only after the presentation of the vowel marks, subjects had to wait for the vowels to appear in order to name those words correctly. Thus, these stimuli provide a baseline for assessing the effect of lagging the vowel marks on naming latencies. When the words were phonologically ambiguous, the effects of lagging the vowel marks on RTs were twice as large as the effects found for unambiguous words, where only one pronunciation was meaningful. These results suggest that subjects adopted two parallel strategies for generating the phonology of the unambiguous printed words: on the one hand they used explicit vowel information using prelexical transformation rules (hence the greater effect of SOA on naming relative to lexical decisions latencies), on the other hand they generated the phonologic structure of the unambiguous words postlexically as well (hence the smaller effects of SOA on naming unambiguous words relative to ambiguous words). These conclusions converge with the results reported by Koriat (1984). Koriat examined the joint effects of semantic priming and vowel mark presentation, and found that semantic priming facilitated naming performance for both pointed and unpointed words, but to the same extent. The presentation of vowel marks speeded naming latencies, but so did a previous presentation of semantic context. Koriat therefore concluded that the pronunciations of unambiguous words are derived both lexically and nonlexically in parallel, and that both processes must be completed and their outcomes compared before the onset of articulation.

Processing lexical ambiguity in Hebrew

Obviously, in the absence of vowel marks, the complete phonemic structure of the letter string in Hebrew cannot be recovered by applying grapheme-to-phoneme conversion rules. Prelexical phonology, therefore, does not appear to be a viable option for the Hebrew reader when presented with unpointed print. He or she is forced to recover the missing phonological information from the lexicon. When the letter string can have only one meaningful pronunciation, the relevant phonologic representation is easy to recover lexically. However, when the letter string has two or more meaningful pronunciations, how does the reader chose among the possible alternatives?

Semantic activation of heterophonic homographs is ordered-accessed

Bentin and Frost (1987) found similar naming latencies for unpointed ambiguous letter strings and for the pointed dominant alternatives. Therefore, they suggested that readers retrieve first the dominant phonological structure of a phonologically ambiguous letter string. The significant delay in naming the subordinate pointed alternatives, relative to the unpointed and the dominant forms of the same letter string, was interpreted as supporting an ordered-access model for the retrieval of phonological information. The naming task, however, cannot disclose covert phonological selection processes. In particular, naming does not reveal whether phonological alternatives, other than the reader's final choice, had been accessed during the process of disambiguation. Although subjects overtly express only one phonological structure, (usually the high-frequency alternative), it is possible that other alternative words were generated but discarded during
the output process. Therefore, a more direct measure was necessary to examine whether more than one phonologic alternative of a heterophonic homograph is automatically activated in reading single words.

The possible activation of the two phonologic alternatives related to Hebrew heterophonic homographs was examined by Frost and Bentin (1992) using a semantic priming paradigm. In this study, subjects were presented with isolated heterophonic homographs as primes, whereas the targets were related to only one of the primes' possible meanings. The targets followed the primes at different SOAs ranging from 100 to 750 ms. It was assumed that if a specific meaning of the prime was accessed, lexical decisions for targets related to that meaning would be facilitated. This experimental paradigm is similar to that used by Simpson and Burgess (1985), who examined the processing of English homophonic homographs (letter strings with two meanings but only one pronunciation). Frost and Bentin (1992) reported that, in the absence of biasing context, both meanings of heterophonic homographs were active at SOAs ranging from 250 to 750 ms from stimulus onset, whereas at a short SOA of 100 ms only the dominant meaning was active.

**Phonologic disambiguation of heterophonic homographs precedes semantic activation**

In another experiment reported in the same study, the processing of heterophonic homographs was compared to the processing of homophonic homographs using an identical technique. It was found that the decay of activation of subordinate meanings of homophonic and heterophonic homographs followed a similar pattern; all meanings remained active as late as 750 ms from stimulus onset. However, when the onset of activation was examined, a different pattern of results was found for heterophonic and homophonic homographs: in contrast to heterophonic homographs, both subordinate and dominant meanings of homophonic homographs were active as early as 100 ms from stimulus onset. Another finding of interest in that study was that across all SOAs, the effects of semantic priming for heterophonic homographs were larger than the effects found for homophonic homographs. Thus, it appears that both the time-course of activating the different meanings, and the amount of activation were influenced by phonological factors.

These results were interpreted to suggest that heterophonic homographs are phonologically disambiguated before the semantic network is accessed. Thus, phonologically ambiguous letter strings refer to different lexical entries, one for each phonological realization (see Figure 2). The alternative lexical entries are automatically activated by the unique orthographical pattern, though at different onset times: in the absence of biasing context the order of activation is determined by the relative word frequency; higher-frequency words are accessed before lower frequency words. As a consequence of the multiple-entry structure and the ordered-access process, heterophonic homographs are phonologically disambiguated prior to any access to semantic information. The overall greater priming effects found for heterophonic than for homophonic homographs suggests that when one lexical unit activates two or more semantic nodes, each of these nodes is activated less than nodes which are unequivocally related to phonological units in the lexicon. Thus, in contrast to lexical decisions, the retrieval of meaning requires the activation of the phonological structure to which the unpointed printed word refers. Note that if meaning were retrieved directly from the orthographic input, no difference should be found between processing homophonic and heterophonic homographs.

One intriguing outcome of the study with Hebrew homographs was that subordinate meanings of both heterophonic and homophonic homographs were still available and used 750 ms from stimulus onset. This result contrasts with the relatively fast decay of subordinate meanings of English homographs (Kellas, Ferraro, & Simpson, 1988; Simpson & Burgess, 1985). Because the decay pattern was similar for both types of Hebrew homographs, the divergence from English should be probably accounted for by language-related factors. One possible source of the different results obtained in Hebrew and in English may be related to the homographic characteristics of the Hebrew orthography. The ubiquity of homography might have shaped the reader's reading strategies. Because ambiguity is so common in reading, the process of semantic and phonologic disambiguation is governed mainly by context. However, the disambiguating context often follows rather than precedes the ambiguous homographs. Therefore, an efficient strategy of processing homographs should require maintaining all the phonologic or semantic alternatives in working memory until the context determines the appropriate one. Note that according to this interpretation the subordinate alternatives do not decay automatically, but remain in memory until disambiguation by context has occurred.
Both phonetic alternatives of heterophonic homographs are automatically activated

Frost (1991) presented additional evidence confirming that both phonologic representations of the ambiguous letter string are automatically activated at some stage after the printed word appears. The aim of this study was to examine directly phonologic and phonetic processing of Hebrew heterophonic homographs. Note that the measurement of semantic facilitation, as used by Frost and Bentin (1992), did not indicate directly whether the presentation of the ambiguous letter string caused the activation of the two phonologic structures related to it, or merely the activation of the two semantic meanings which were accessed directly from the print. To solve this problem, Frost (1991) employed a speech detection task and a task consisting of matching simultaneously presented printed and spoken words. These tasks have been previously shown to detect phonetic and phonologic activation that emerges from the visual presentation of meaningful letter strings (Frost, 1991; Frost & Katz, 1989; Frost, Repp, & Katz, 1988).

The speech detection task is based on an auditory illusion previously reported by Frost et al. (1988). When an amplitude-modulated noise generated from a spoken word is presented simultaneously with the word’s printed version, the noise sounds more speechlike than when the print is absent. This auditory illusion suggests that subjects automatically detect correspondences between amplitude envelopes of spoken words and printed stimuli. This speech detection task was employed to examine the processing of Hebrew heterophonic homographs. Subjects were presented with speech-plus-noise and with noise-only trials, and were instructed to detect the speech in the noise. The auditory stimuli were simultaneously presented with printed letter strings that represented two phonologic meaningful structures (heterophonic homographs), one dominant and the other subordinate. In these trials the printed homographs were presented in their pointed form and were therefore disambiguated; that is, the vowel marks unequivocally pointed to either the dominant or the subordinate alternative. In these trials the matching of the visual printed words to the spoken words did not require any ambiguity resolution. In other trials the homographs appeared unpointed, and consequently could be read in two ways. In those trials the outcome of matching the visual printed words to the spoken words was dependent on the specific phonologic alternative generated from the ambiguous consonant string. The aim of the experiment was to compare the decision time for pointed and unpointed print. The results demonstrated that matching the unpointed printed forms of heterophonic homographs to the dominant and subordinate spoken alternatives that were presented auditorily was as fast as matching the
pointed unambiguous forms to the respective spoken words. Therefore, these results confirm that both phonologic alternatives were automatically generated from the letter string.

In conclusion, the resolution of phonologic ambiguity in unpointed print is a routine procedure for the Hebrew reader. Our findings suggest that the Hebrew reader develops an orthographic lexicon that serves as an interface to the phonologic lexicon. Each orthographic entry is related to one, two, or more phonologic entries. Lexical decisions in Hebrew are given in reference to this orthographic interface prior to the activation of the phonologic lexicon. However, the activation of an orthographic entry results in the automatic activation of all phonologic entries in the mental lexicon. Semantic activation follows the activation of phonologic entries. Since, in general, while reading, the context disambiguates the phonologically abstract letter string, all phonologic and semantic alternatives remain available for relatively longer periods than in other orthographies such as English. Although all phonologic alternatives are activated following the presentation of the unpointed letters, the more frequent alternative acquires dominance when articulation is required.

**Morphologic processing in Hebrew**

In the present discussion of Hebrew morphology we will limit ourselves to the processing of roots by the reader. Because the root is the most important determinant of meaning in both spoken and written Hebrew, it has a unique status within the word. Both inflections and derivations in Hebrew modify the root by adding to it prefixes, infixes, and suffixes following specific word patterns. As mentioned in the beginning of this chapter, the root usually specifies a constrained semantic field that constitutes the basic information regarding the meaning of the word. Thus it is fairly reasonable to assume that its extraction from the whole word, whether spoken or written, is a primary process in the analysis of spoken or printed words. We cannot report any data regarding the perception of speech. However, the psychological reality of the status of the root in printed words was examined in several studies.

**Morphologic relatedness causes long lasting repetition effects**

The preferred technique for investigating morphologic processing in Hebrew was to examine the contribution of morphologic relatedness to pattern of facilitation in the repetition priming task (Bentin & Feldman, 1989; Feldman & Bentin, forthcoming). Bentin and Feldman (1989) examined the effects of morphologic repetition at lag 0 and 15 on lexical decision to the target. Specifically, they compared the effects of pure semantic relatedness, pure morphologic relatedness, and combined semantic and morphologic relatedness, on lexical decisions. In the pure semantic relatedness condition primes and targets consisted of words having different roots but related meanings. In the pure morphologic relatedness condition primes and targets shared the same root but had different meanings (as in the example depicted in Figure 1). Finally, in the combined relatedness condition primes and targets shared both root and meaning. The results showed that semantic relatedness facilitated lexical decisions only at lag 0, whereas pure morphologic relatedness exerted its effect on lexical decisions at lag 0 and 15. Semantic facilitation was greater than morphologic facilitation at lag 0. Facilitation of combined relatedness was as strong as semantic relatedness at lag 0 and similar to pure morphologic relatedness at lag 15. This outcome suggests that semantic activation and morphologic activation have different time courses and arise from two different sources. The presentation of a word containing the root has longer lasting beneficial effects on lexical decisions relative to mere semantic relatedness. Thus, it appears that a previous presentation of the abstract Hebrew root aids lexical processes such as the retrieval of related words and word meanings even at long repetition lags.

**Roots are extracted by the reader while processing printed words**

In another study, Feldman, Frost, & Dar (forthcoming) examined the ability of skilled readers to detach the phonologic patterns from the roots. This study was based on the segment-shifting task proposed by Feldman (1991). In the segment-shifting task subjects are presented with a printed word in which one segment is underlined. The subjects are required to detach the underlined segment from the word and append it to another word presented underneath. The subjects have to pronounce the second word with the new segment (usually appended to its end) as quickly as possible. The experimental conditions typically consist of underlining a segment that is a suffix morpheme in one word, but not in another (e.g., ER is a suffix morpheme in DRUMMER but not in SUMMER). Is it easier to detach ER from DRUMMER than from SUMMER?

The segment-shifting task was originally employed by Feldman in English and Serbo-
Croatian. These languages are characterized by concatenative morphology where morphologically complex words are constructed from discrete morphemic constituents that are linked linearly: There is a base morpheme to which other elements are appended so as to form a sequence. In languages with concatenative morphology, suffixes and prefixes are regularly appended to the base morpheme in a manner that preserves its phonological and orthographic structure. In contrast to English and Serbo-Croatian, Hebrew is usually characterized by a nonconcatenative morphology. In Hebrew the phonologic word pattern is an infix, not a prefix or a suffix. It is superimposed on the root and changes both its phonologic and its orthographic structure (see the example of “dover” in Figure 1).

Experiments that employed the segment-shifting task in English and Serbo-Croatian yielded straightforward results: It is easier to detach a segment that serves as a morphemic suffix appended to a base morpheme than to detach the same sequence of letters when it is an integral part of a word that cannot be decomposed into morphemic constituents. This outcome suggests that the processing of morphologically complex words in languages with concatenated morphology entails morphemic decomposition. Such decomposition is relatively easy and straightforward when the morphemic constituents are linked linearly. In contrast to English and Serbo-Croatian, the decomposition of Hebrew derivations and inflections into root and word pattern is not as straightforward. This is because the phonemes of the root and the phonemes of the word pattern are intermixed.

Feldman et al. (forthcoming) took advantage of the fact that although formally all words in Hebrew can be defined as containing roots, not all roots are productive. Roots are considered productive if they can be inflected, and other words can be derived from them. A root is considered nonproductive if it cannot be inflected and is therefore contained in only one Hebrew word. Many words in Hebrew form a unique phonemic sequence that does not lend itself to inflections or derivations. Feldman et al. asked whether a specific phonologic word pattern can be detached more easily from words that contain productive roots than from words that contain nonproductive roots.

The experiment was similar to the typical segment-shifting task experiment. Subjects were presented with pointed words and were required to detach the sequence of vowels from the words, to superimpose them on a nonword consonant cluster, and to name it. The results showed that it was easier to detach the vowels from three consonants that were a productive root than to detach them from three letters that were not. In a second experiment similar and even stronger effects were obtained when the word patterns were not merely vowels but consisted of a sequence of vowels and consonants. These results suggest that productive roots have a special status for the Hebrew speaker and reader. Their psychological reality is reflected by their salience relative to the other letters and phonemes constituting the word. It appears that the presentation of a printed word containing a productive root results in the automatic detection of this root, such that the letters of a word are parsed into letters belonging to the root and letters not belonging to it. The important aspect of this morphologic decomposition is that the root letters do not have to appear in adjacent position (as in the second experiment). Even if they are dispersed within the word they are automatically extracted by the reader. We believe that a similar process can be demonstrated in the recognition and understanding of spoken words as well. That is, the phonemes belonging to the root have a unique psychological reality. However, this suggestion requires further investigation.

CONCLUSIONS

The pointed and unpointed Hebrew orthography presents an opportunity to examine reading processes when full or partial phonologic information is conveyed by print. This provides a significant methodological tool for investigating the effects of orthographic depth on visual word recognition, yet avoiding the pitfalls of cross-language designs. Research in reading Hebrew suggests that reading strategies are affected by the presentation or the omission of vowel marks. Efficient reading of unpointed text is based on fast recognition of orthographic clusters that become phonologically and semantically unequivocal given the available context. In contrast, the presentation of vowel marks induces a phonological processing of the printed words, which is often characteristic of shallow orthographies. This suggests that the reader of Hebrew adopts flexible reading strategies that take advantage of all possible phonemic information provided by the print.

REFERENCES


**FOOTNOTES**

*In L. Katz & R. Frost (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 27-44). Amsterdam: Elsevier Science Publishers (1992).*

1Department of Psychology, The Hebrew University, Jerusalem.