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Prelexical and Postlexical Strategies in Reading: Evidence From a Deep and a Shallow Orthography

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The validity of the orthographic depth hypothesis (ODH) was examined in Hebrew by employing pointed (shallow) and unpointed (deep) print. Experiments 1 and 2 revealed larger frequency effects and larger semantic priming effects in naming with unpointed print than with pointed print. In Experiments 3 and 4, subjects were presented with Hebrew consonantal strings that were followed by vowel marks appearing at stimulus onset asynchronies ranging from 0 ms (simultaneous presentation) to 300 ms from the onset of consonant presentation. Subjects were inclined to wait for the vowel marks to appear even though the words could be named unequivocally using lexical phonology. These results suggested that prelexical phonology was the default strategy for readers in shallow orthographies, providing strong support for the ODH.

Most early studies of visual word recognition were carried out in the English language. This state of affairs was partly due to an underlying belief that reading processes (as well as other cognitive processes) are universal, and therefore studies in English are sufficient to provide a complete account of the processes involved in recognizing printed words. In the last decade, however, studies in orthographies other than English have become more and more prevalent. These studies have in common the view that reading processes cannot be explained without considering the reader's linguistic environment in general, and the characteristics of his or her writing system in particular.

Various writing system have evolved over time in different cultures. These writing systems, whether logographic, syllabic, or alphabetic, typically reflect the language's unique phonology and morphology, representing them in an effective way (Mattingly, 1992; Scheerer, 1986). The match between writing system and language insures a degree of efficiency for the reading and the writing process (for a discussion, see Katz & Frost, 1992). Theories of visual recognition differ in their account of how the different characteristics of writing systems affect reading performance. One such characteristic that has been widely investigated is the way the orthography represents the language's surface phonology.

The transparency of the relation between spelling and phonology varies widely between orthographies. This variance can often be attributed to morphological factors. In some languages (e.g., in English), morphological variations are captured by phonologic variations. The orthography, however, was designed to preserve primarily morphologic information. Consequently, in many cases, similar spellings denote the same morpheme but different phonologic forms: The same letter can represent different phonemes when it is in different contexts, and the same phoneme can be represented by different letters. The words *steal* and *stealth*, for example, are similarly spelled because they are morphologically related. Since in this case, however, a morphologic derivation resulted in a phonologic variation, the cluster "ea" represents both the sounds [*i*] and [*e*]. Thus, alphabetic orthographies can be classified according to the transparency of their letter to phonology correspondence. This factor is usually referred to as *orthographic depth* (Katz & Feldman, 1981; Klima, 1972; Liberman, Liberman, Mattingly, & Shankweiler, 1980; Lukatela, Popadic, Ognjenovic, & Turvey, 1980). An orthography that represents its phonology unequivocally following grapheme–phoneme simple correspondences is considered shallow, while in a deep orthography the relation of orthography to phonology is more opaque.

The effect of orthographic depth on reading strategies has been the focus of recent and current controversies (e.g., Besner & Smith, 1992; Frost, Katz, & Bentin, 1987). In general, the argument revolves around the question of whether differences in orthographic depth lead to differences in processing printed words. What is called the orthographic depth hypothesis (ODH) suggests that it does. The ODH suggests that shallow orthographies can easily support a word recognition process that involves the printed word's phonology. This is because the phonologic structure of the printed word can be easily recovered from the print by applying a simple process of grapheme-to-phoneme conversion (GPC). For example, in the Serbo-Croatian writing system the letter-to-phoneme correspondence is consistent and the spoken language itself is not phonologically complex. The correspondence between spelling and pronunciation is so simple and direct that a reader of this orthography can expect that phonological recoding will always result in an accurate representation of the word intended by the writer. A considerable amount of evidence now supports the claim that phonological recoding is extensively used by

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readers of Serbo-Croatian (see Carello, Turvey, & Lukatela, 1992, for a review). In contrast to shallow orthographies, deep orthographies like English or Hebrew encourage readers to process printed words by referring to their morphology via the printed word's visual-orthographic structure. In deep orthographies, lexical access is based mainly on the word's orthographic structure, and the word's phonology is retrieved from the mental lexicon. This is because the relation between the printed word and its phonology are more opaque and prelexical phonologic information cannot be easily generated (e.g., Frost & Bentin, 1992b; Frost et al., 1987; Katz & Feldman, 1983).

The ODH's specific predictions mainly refer to the way a printed word's phonology is generated in the reading process. Because readers of shallow orthographies have simple, consistent, and relatively complete connections between graphemes and subword pronunciation, they can recover most of a word's phonological structure prelexically, by assembling it directly from the printed letters. In contrast, the opaque relation of subwords, segments, and phonemes in deep orthographies prevents readers from using prelexical conversion rules. For these readers, the more efficient process of generating the word's phonologic structure is to rely on a fast visual access of the lexicon and to retrieve the word's phonology from it. Thus, phonology in this case is lexically addressed not prelexically assembled. Therefore, according to the ODH, the difference between deep and shallow orthographies is the amount of lexical involvement in pronunciation. This does not necessarily entail specific predictions concerning lexical decisions and lexical access, or how meaning is accessed from print.

The specific predictions of the ODH must be discussed with reference to the tools of investigation employed by the experimenter. The issue to be clarified here is what serves as a valid demonstration that phonology is mainly prelexical (assembled) or postlexical (addressed). In general, measures of latencies and error rates for lexical decisions or naming are monitored. The idea is that lexical involvement in pronunciation leaves characteristic traces. The first question to be examined is, therefore, whether the lexical status of a word affects naming latencies. Lexical search results in frequency effects and in lexicality effects: Frequent words are named faster than nonfrequent words, and words are named faster than nonwords (see Balota & Chumbley, 1984, for a discussion of this point). Thus, one trace of postlexical phonology is that naming latencies and lexical decision latencies are similarly affected by the lexical status of the printed stimulus (e.g., Katz & Feldman, 1983). If phonology is assembled from print prelexically, smaller effects related to the word's lexical status should be expected, and consequently lexical status should affect naming and lexical decisions differently. A second method of investigation involves the monitoring of semantic priming effects in naming (see Lupker, 1984; Neely, 1991, for a review). If pronunciation involves postlexical phonology, strong semantic priming effects will be revealed in naming. In contrast, if pronunciation is carried out using mainly prelexical phonology, naming of target words would be less facilitated by semantically related primes.

Keeping these tools of investigation in mind, the exact predictions of the ODH can be now fully described. Two versions of the hypothesis exist in the current literature. What can be called the strong ODH claims that in shallow orthographies, the complete phonological representations can be derived exclusively from only the prelexical translation of subword spelling units (letter or letter clusters) into phonological units (phonemes, phoneme clusters, and syllables). According to this view, readers of shallow orthographies perform a phonological analysis of the word based only on a knowledge of these correspondences. Rapid naming, then, is a result of this analytic process only, and does not involve any lexical information (see Katz & Frost, 1992, for a discussion). In contrast to the strong ODH, a weaker version of the ODH can be proposed. According to the weak version of the ODH, the phonology needed for the pronunciation of printed words comes both from prelexical letter-phonology correspondences and from stored lexical phonology. The latter is the result of either an orthographic addressing of the lexicon (i.e., from a whole-word or whole-morpheme spelling pattern to its stored phonology), or from a partial phonologic representation that was assembled from the print and was unequivocal enough to allow lexical access. The degree to which the prelexical process is active is a function of the depth of the orthography; prelexical analytic processes are more functional in shallow orthographies. Whether or not prelexical processes actually dominate orthographic processing for any particular orthography is a question of the demands the two processes make on the reader's processing resources (Katz & Frost, 1992).

It is easy to show that the strong form of the ODH is untenable. It is patently insufficient to account for pronunciation even in shallow orthographies like Spanish, Italian, or Serbo-Croatian. This is so because these orthographies do not represent syllable stress and, even though stress is often predictable, this is not always the case. For example, in Serbo-Croatian, stress for two-syllable words always occurs on the first syllable, but not always for words of more than two syllables. These words can be pronounced correctly only by reference to lexically stored information. The issue of stress assignment is even more problematic in Italian, where stress patterns are much less predictable. In Italian, many pairs of words differ only in stress, which provides the intended semantic meaning (Colombo & Tabossi, 1992; Laudanna & Caramazza, 1992).

Several studies have argued for the obligatory involvement of prelexical phonology in Serbo-Croatian (e.g., Turvey, Feldman, & Lukatela, 1984) or in English (Perfetti, Bell, & Delaney, 1988; Perfetti, Zhang, & Berent, 1992; Van Orden, 1987). Note that the weaker version of the ODH is not inconsistent with these claims as long as it is not claimed that naming is achieved exclusively by prelexical analysis. All alphabetic orthographies may make some use of prelexically derived phonology for word recognition. According to the weak form of the ODH, shallow orthographies should make more use of it than deep orthographies, because prelexical phonology is more readily available in these orthographies. Substantial prelexical phonology may be generated inevitably when reading Serbo-Croatian, for example. This phonological representation may be sufficient for lexical access, but not necessarily for pronunciation. The complete analysis of the word's phonologic and phonetic structure may involve lexical information as well (Carello et al., 1992).

Evidence concerning the validity of the ODH comes from within- and cross-language studies. But note that single-language experiments are adequate only for testing the strongest form of the ODH. The strong ODH requires lexical access and pronunciation to be accomplished entirely on the basis of phonological information derived from correspondences between subword spelling and phonology. That is, the reader's phonological analysis of the printed word, based on his or her knowledge of subword letter-sound relationships, is the only kind of information that is allowed. Thus, merely showing lexical involvement in pronunciation in a shallow orthography would provide a valid falsification of the strong ODH (Sebastian-Galles, 1991; Seidenberg & Vidanovic, 1985). However, the demonstration of lexical effects in shallow orthographies cannot in itself be considered evidence against the weak ODH, and a different methodology is necessary to test it. Because it refers to the relative use of prelexical phonologic information in word recognition in different orthographies, experimental evidence bearing on the weak ODH should come mainly from cross-language studies. More important, because the weak ODH claims that readers in shallow orthographies do not use the assembled routine exclusively, the evidence against it cannot come from single-language studies by merely showing the use of the addressed routine in shallow orthographies (e.g., Sebastian-Galles, 1991).

The experimental evidence supporting the weak ODH is abundant. Katz and Feldman (1983) compared semantic priming effects in naming and lexical decision in English and Serbo-Croatian, and demonstrated that while semantic facilitation was obtained in English for both lexical decision and naming, in Serbo-Croatian semantic priming facilitated only lexical decision. Similarly, a comparison of semantic priming effects in naming in English and Italian showed greater effects in the deeper English than in the shallower Italian orthography (Tabossi & Laghi, 1992). A study by Frost et al. (1987) involved a simultaneous comparison of three languages, Hebrew, English, and Serbo-Croatian, and confirmed the hypothesis that the use of prelexical phonology in naming varies as a function of orthographic depth. Frost et al. showed that the lexical status of the stimulus (its being a high- or a low-frequency word or a nonword) affected naming latencies in Hebrew more than in English, and in English more than in Serbo-Croatian. In a second experiment, Frost et al. showed a relatively strong effect of semantic facilitation in Hebrew (21 ms), a smaller but significant effect in English (16 ms), and no facilitation (0 ms) in Serbo-Croatian.

Frost & Katz (1989) examined the effects of visual and auditory degradation on the ability of subjects to match printed to spoken words in English and Serbo-Croatian. They showed that both visual and auditory degradation had a much stronger effect in English than in Serbo-Croatian, regardless of word frequency. These results were explained by an extension of an interactive model which rationalized the relationship between the orthographic and phonologic systems in terms of lateral connections between the systems at all of their levels. The structure of these lateral connections was determined by the relationship between spelling and phonology in the language: simple isomorphic connections between graphemes and phonemes in the shallower Serbo-Croatian, but more complex, many-to-one, connections in the deeper English. Frost and Katz argued that the simple isomorphic connections between the orthographic and the phonologic systems in the shallower orthography enabled subjects to restore both the degraded phonemes from the print and the degraded graphemes from the phonemic information, with ease. In contrast, in the deeper orthography, because the degraded information in one system was usually consistent with several alternatives in the other system, the buildup of sufficient information for a unique solution to the matching judgment was delayed, so the matching between print and degraded speech, or between speech and degraded print, was slowed.

The psychological reality of orthographic depth is not unanimously accepted. Although it is generally agreed that the relation between spelling and phonology in different orthographies might affect reading processes (especially reading acquisition) to a certain extent, there is disagreement as to the relative importance of this factor. What I will call here *the alternative view* argues that the primary factor determining whether or not the word's phonology is assembled pre- or postlexically is not orthographic depth but word frequency. The alternative view suggests that in any orthography, frequent words are very familiar as visual patterns. Therefore, these words can easily be recognized through a fast visually based lexical access which occurs before a phonologic representation has time to be generated prelexically from the print. For these words, phonologic information is eventually obtained, but only postlexically, from memory storage. According to this view, the relation of spelling to phonology should not affect recognition of frequent words. Since the orthographic structure is not converted into a phonologic structure by use of grapheme-to-phoneme conversion rules, the depth of the orthography does not play a role in the processing of these words. Orthographic depth exerts some influence, but only on the processing of low-frequency words and nonwords. Since such verbal stimuli are less familiar, their visual lexical access is slower, and their phonology has enough time to be generated prelexically (Baluch & Besner, 1991; Seidenberg, 1985; Tabossi & Laghi, 1992).

A few studies involving cross-language research support the alternative view. Seidenberg (1985) demonstrated that in both English and Chinese, naming frequent printed words was not affected by phonologic regularity. This outcome was interpreted to mean that, in logographic as in alphabetic orthographies, the phonology of frequent words was derived postlexically, after the word had been recognized on a visual basis. Moreover, in another study, Seidenberg and Vidanovic (1985) found similar semantic priming effects in naming frequent words in English and Serbo-Croatian, suggesting again that the addressed routine plays a major role even in the shallow Serbo-Croatian.

Several studies in Japanese were interpreted as providing support for the alternative view. Although these studies were carried out within one language, they could in principle furnish evidence in favor or against the weak ODH because they examined reading performance in two different writing systems that are commonly used in Japanese: the deep, logographic Kanji and the shallower, syllabic Hiragana and Katakana. However, the relevance of these studies to the debate concerning the weak ODH is questionable, as I will point out. Besner and Hildebrant (1987) showed that words that were normally written in Katakana were named faster than words written in Katakana that were transcribed from Kanji. They argued that these results suggest that readers of the shallow Katakana did not name the transcribed words using the assembled routine, as otherwise no difference should have emerged in naming the two types of stimuli. In another experiment, Besner, Patterson, Lee, and Hildebrant (in press) showed that naming words that are normally seen in Katakana were named slower if they were written in Hiragana and vice versa. This outcome suggests that orthographic familiarity plays a role even in reading the shallower syllabic Japanese orthographies. Taken together, the results from the Japanese study provide strong evidence against the strong ODH, but they do not contradict the weak ODH. Although these studies compare reading performance in two writing systems, they merely show that readers of the shallower Japanese syllabary do not use the assembled routine exclusively, but use the addressed routine as well. These conclusions, however, are actually the basic tenets of the weak ODH.

More damaging to the weak ODH is a recent study by Baluch and Besner (1991), who employed a within-language between orthography design in Persian that was similar to the one in Japanese. In this study the authors took advantage of the fact that some words in Persian are phonologically transparent whereas other words are phonologically opaque. This is because three of the six vowels of written Persian are represented in print as diacritics and three are represented as letters. Because (as in Hebrew) fluent readers do not use the pointed script, words that contain vowels represented by letters are phonologically transparent, whereas words that contain vowels represented by diacritics are phonologically opaque. Baluch and Besner demonstrated similar semantic priming effects in naming phonologically transparent and phonologically opaque words of Persian, provided that nonwords were omitted from the stimulus list. These results were interpreted to suggest that the addressed routine was used in naming both types of words.

Thus, when the weak ODH and the traditional alternative view are contrasted, it appears that they differ in one major claim concerning the preferred route of the cognitive system for obtaining the printed word's phonology. The alternative view suggests that in general visual access of the lexicon is direct and requires fewer cognitive resources. Moreover, the extraction of phonological information from the mental lexicon is more or less effortless relative to the extraction of phonological information prelexically. Hence, the default of the cognitive system in reading is the use of addressed phonology. The weak ODH denies that the extraction of phonological information from the mental lexicon is effortless. On the contrary, based on findings showing extensive phonologic recoding in shallow orthographies, its working hypothesis is that if the reader can successfully employ prelexical phonological information, then it will be used first; the easier it is, the more often it will be used. Thus, the default of the cognitive system in word recognition is the use of prelexical rather than addressed phonology. If the reader's orthography is a shallow one with uncomplicated, direct, and consistent correspondences between letters and phonology, then the reader will be able to use such information with minimal resources for lexical access. The logic for the ODH lies in a simple argument. The so called fast, effortless, visual route is available for readers in all orthographies, including the shallow ones. If in spite of that it can be demonstrated that readers of shallow orthographies do prefer prelexical phonological mediation over visual access, it is because it is more efficient and faster for these readers.

The present study addresses this controversy by looking at a deeper orthography, namely Hebrew. In Hebrew, letters represent mostly consonants, while vowels can optionally be superimposed on the consonants as diacritical marks. The diacritical marks, however, are omitted from most reading material, and are found only in poetry, children's literature, and religious texts. In addition, like other Semitic languages, Hebrew is based on word families derived from triconsonantal roots. Therefore, many words (whether morphologically related or not) share a similar or identical letter configuration. If the vowel marks are absent, a single printed consonantal string usually represents several different spoken words. Thus, in its unpointed form, the Hebrew orthography does not convey to the reader the full phonemic structure of the printed word, and the reader is often faced with phonological ambiguity. In contrast to the unpointed orthography, the pointed orthography is a very shallow writing system. The vowel marks convey the missing phonemic information, making the printed word phonemically unequivocal. Although the diacritical marks carry mainly vowel information, they also differentiate in some instances between fricative and stop variants of consonants. Thus the presentation of vowels considerably reduces several aspects of phonemic ambiguity (see Frost & Bentin, 1992b, for a discussion).

Several studies have shown that lexical decisions to Hebrew phonologically ambiguous words are given prior to any phonological disambiguation, suggesting that lexical access in unpointed Hebrew is accomplished more often via orthographic representations than via phonological recodings of the orthography (Bentin, Bargai, & Katz, 1984; Bentin & Frost, 1987; Frost, 1992; Frost & Bentin, 1992a; and see Frost & Bentin, 1992b, for a review). The purpose of the present study was to show that even the reader of Hebrew who is exposed almost exclusively to unpointed print and generally uses the lexical addressed routine, prefers to use the prelexical assembled routine when possible. Note that the probability of extending the cross-language findings (e.g., Frost et al., 1987) to a within-Hebrew experimental design suffers from the fact that readers in general are used to regularly employing strategies of reading that arise from the characteristics of their orthography. Obviously, if it can be shown that even in spite of this factor Hebrew readers are willing to alter their reading strategy and adopt a prelexical routine, it will certainly provide very significant evidence in favor of the ODH.

Experiment 1

In Experiment 1, lexical decision and naming performance with pointed and unpointed print were compared. The aim of

	Unpointed	Pointed
Hebrew print	פסנתר	פְּסַנְתֵּר
Phonologic structure	/ psanter /	
Semantic meaning	Piano	

Figure 1. Example of the unpointed and the pointed forms of a Hebrew printed word.

the experiment was to assess the effects of lexical factors on naming performance relative to lexical decision in the deep and shallow forms of the Hebrew orthography. This experimental design is very similar to that employed by Frost et al. (1987) in the first experiment of their multilingual study. Frost et al. found that in unpointed Hebrew the lexical status of the stimuli affected lexical decision latencies in the same way that it affected naming latencies. In contrast, in English and in Serbo-Croatian the pronunciation task was much less affected by the lexical status of the stimuli. The shallower the orthography, the more naming performance deviated from lexical decision performance. This outcome confirmed that, in unpointed Hebrew, phonology was generated mainly using the addressed routine, whereas in the shallower English orthography the assembled routine had a more significant role. Finally, in the shallowest orthography, Serbo-Croatian, the assembled routine dominated the addressed routine, resulting in a nonsignificant frequency effect. The purpose of Experiment 1 was to investigate whether a similar gradual deviation of naming from lexical decision performance would be observed in pointed relative to unpointed Hebrew. If the weak ODH is correct, then the reader of Hebrew should use the assembled routine to a greater extent when naming pointed print than when naming unpointed print.

Method

Subjects. One hundred and sixty undergraduate students from the Hebrew University, all native speakers of Hebrew, participated in the experiment for course credit or for payment.

Stimuli and design. The stimuli were 40 high-frequency words, 40 low-frequency words, and 80 nonwords. All stimuli were three to five letters long, and contained two syllables with four to six phonemes. The average number of letters and phonemes were similar for the three types of stimuli. All words could be pronounced as only one meaningful word. Nonwords were created by altering randomly one or two letters of high- or low-frequency real words that were not employed in the experiment. The nonwords were all pronounceable and did not violate the phonotactic rules of Hebrew. In the absence of a reliable frequency count in Hebrew, the subjective frequency of each word was estimated using the following procedure: A list of 250 words was presented to 50 undergraduate students, who rated the frequency of each word on a 7-point scale from very infrequent (1) to very frequent (7). The rated frequencies were averaged across all 50 judges, and all words in the present study were selected from this pool. The average frequency of the high-frequency words was 4.0, whereas the average frequency of the low-frequency words was 2.0. Examples of pointed and unpointed Hebrew words are presented in Figure 1.

There were four experimental conditions: the stimuli could be presented pointed or unpointed, for naming or for lexical decision. Forty different subjects were tested in each experimental condition. This blocked design was identical to that of the Frost et al. (1987) study.

Procedure and apparatus. The stimuli were presented on a Macintosh SE computer screen, and a bold Hebrew font, size 24, was used. Subjects were tested individually in a dimly lighted room. They sat 70 cm from the screen so that the stimuli subtended a horizontal visual angle of 4° on the average. The subjects communicated lexical decisions by pressing a "yes" or a "no" key. The dominant hand was always used for the "yes" response. In the naming task, response latencies were monitored by a Mura-DX 118 microphone connected to a voice key. Each experiment started with 16 practice trials, which were followed by the 160 experimental trials presented in one block. The trials were presented at a 2.5 intertrial interval.

Results

Means and standard deviations of response times (RTs) for correct responses were calculated for each subject in each of the four experimental conditions. Within each subject/condition combination, RTs that were outside a range of 2 standard deviations from the respective mean were excluded, and the mean was recalculated. Outliers accounted for less than 5% of all responses. This procedure was repeated in all the experiments of the present study.

Mean RTs and error rates for high-frequency words, low-frequency words, and nonwords in the different experimental conditions are presented in Table 1.[1] Point presentation had very little effect in the lexical decision task. In contrast, in the naming task the effect of frequency and lexical status of the stimulus were more pronounced in the unpointed presentation than in the pointed presentation. Moreover, naming was more similar to lexical decision performance in unpointed than in pointed print.

The statistical significance of these differences was assessed by an analysis of variance (ANOVA) across subjects, F_1, and across stimuli, F_2, with the main factors of stimulus type (high-frequency words, low-frequency words, nonwords), point presentation (pointed, unpointed), and task (naming, lexical decision). The main effect of stimulus type was significant, $F_1(2, 312) = 267.0, MS_e = 1{,}550, p < 0.001$; $F_2(2, 157) = 119.0, MS_e = 4{,}705, p < 0.001$. The main effects of point presentation and task were not significant in the subject analysis, $F_1(1, 156) = 1.7, MS_e = 21{,}506, p < 0.2$; $F_1(1, 156) = 2.1, MS_e = 21{,}506, p < 0.2$, respectively, but were significant in the stimulus analysis, $F_2(1, 157) = 63.7, MS_e = 3{,}258, p < 0.001$; $F_2(1, 157) = 23.1, MS_e = 3{,}258, p < 0.001$, respectively. Point presentation interacted with task, $F_1(1, 156) = 4.3, MS_e = 21{,}506, p < 0.04$; $F_2(1, 157) = 97.9, MS_e = 1{,}877, p < 0.001$.

[1] The error rates presented in this study should be evaluated with care because the criteria for assessing an error in pointed and unpointed print are different. While in unpointed print any pronunciation consistent with the consonants only is considered correct, in pointed print any pronunciation that is inconsistent with the explicit vowel information is considered an error. This is of special significance when evaluating the nonwords data. In unpointed print subjects have much greater flexibility in naming nonwords than in pointed print, hence the larger error rates in the pointed condition.

Table 1
Reaction Times (RTs; in Milliseconds) and Percent Errors in the Lexical Decision and Naming Tasks for High-Frequency Words, Low-Frequency Words, and Nonwords in Unpointed and Pointed Print

Task	Unpointed print			Pointed Print		
	High-frequency words	Low-frequency words	Non-words	High-frequency words	Low-frequency words	Non-words
Lexical Decision						
RT	529	617	659	545	627	664
% error	4	2	5	5	5	5
Naming						
RT	569	597	664	541	550	604
% error	0	6	2	0	2	9

Stimulus type interacted both with point presentation and with task, $F_1(2, 312) = 3.0, MS_e = 1{,}550, p < 0.05$; $F_2(2, 157) = 11.9, MS_e = 832, p < 0.001$; $F_1(2, 312) = 30.0, MS_e = 1{,}550, p < 0.001$; $F_2(2, 157) = 17.4, MS_e = 3{,}258, p < 0.001$, respectively. The three-way interaction did not reach significance. This was probably due to a similar slowing of nonword latencies relative to the low-frequency words in the two prints. The difference between naming pointed and unpointed presentation was most conspicuous when examining the effect of word frequency. A Tukey-*a* post hoc analysis ($p < 0.05$) revealed that while there was a significant frequency effect in naming unpointed print (28 ms), there was no significant frequency effect in naming pointed print (9 ms). Finally, the correlation of RTs in the naming and the lexical decision task was calculated for both types of print presentation. RTs in the two tasks were highly correlated in the unpointed presentation ($r = 0.56$), but much less so in the pointed presentation ($r = 0.28$). This suggests that the lexical status of the stimuli affected lexical decision and naming similarly in unpointed print but not in pointed print.

Discussion

The results of Experiment 1 replicate to a certain extent the findings of Frost et al. (1987), with a within-language, between-orthography design. The pattern of naming and lexical decision latencies in unpointed Hebrew was almost identical to the pattern obtained in the Frost et al. study. However, the relations of lexical decision to naming latencies in pointed Hebrew were similar to those obtained by Frost et al. in the shallower orthographies of English and Serbo-Croatian. The patterns of response times in naming and lexical decisions were fairly similar in unpointed print. This suggests a strong reliance on the addressed routine in naming when the vowel marks were not present. In contrast, naming deviated from the pattern obtained in the lexical decision task when the vowel marks were presented. The frequency effect almost disappeared, and the overall difference between naming high-frequency words and nonwords was considerably reduced. This outcome suggests that the presentation of vowel marks encouraged the readers to adopt a strategy of assembling the printed word phonology by using prelexical conversion rules. Note, however, that although the overall difference between high-frequency words and nonwords was smaller in pointed print than in unpointed print, the difference between low-frequency words and nonwords were fairly similar in the two conditions (54 in pointed print vs. 67 in unpointed print). This outcome is not fully consistent with a prelexical computation of printed stimuli in the shallow pointed print. A possible explanation for the unexpected slow naming latencies for pointed nonwords is that although phonology could be easily computed prelexically in pointed print, subjects were also sensitive to the familiarity of the printed stimuli. Readers in Hebrew read mostly unpointed print but have a large experience in reading pointed print as well. Because they are obviously more familiar with reading words than nonwords, the slower latencies for nonwords could be attributed to a response factors rather than factor related to the computation of phonology.

Experiment 2

The aim of Experiment 2 was to examine the effects of semantic facilitation in the naming task when pointed and unpointed words are presented. Semantic priming effects in the naming task have been used in several studies to monitor the extent of lexical involvement in pronunciation (e.g., Baluch & Besner, 1991; Frost et al., 1987; Tabossi & Laghi, 1992). In general, it has been shown that in languages with deep orthographies such as English, semantic facilitation in naming can easily be obtained, although the effects are usually smaller than the effect obtained in the lexical decision task (Lupker, 1984; Neely, 1991). In contrast, in shallow orthographies such as Serbo-Croatian, semantic priming effects were not obtained in some studies (e.g., Frost et al., 1987; Katz & Feldman, 1983), but have been shown in other studies (e.g., Carello, Lukatela, & Turvey, 1988; Lukatela, Feldman, Turvey, Carello, & Katz, 1989).

An examination of the weak version of the ODH entails, however, a comparison of semantic priming effects in a deep and a shallow orthography. Katz and Feldman (1983) showed greater semantic facilitation in English than in Serbo-Croatian. Similarly, Frost et al. (1987) demonstrated a gradual decrease in semantic facilitation from Hebrew (deepest orthography) to English (shallower) to Serbo-Croatian (shallowest). Similar results were suggested by Tabossi and Laghi (1992) who compared English to Italian. Recently, Baluch and Besner (1991) have challenged these findings, suggesting that all those cross-language differences were obtained because nonwords

Table 2
Reaction Times (RTs; in Milliseconds) and Percent Errors for Related and Unrelated Targets With Pointed and Unpointed Print

Target	Unpointed print	Pointed print
Unrelated		
RT	531	512
% error	1	2
Related		
RT	509	503
% error	4	1
Priming effect	22	9

were included in the stimulus lists. According to their proposal the inclusion of nonwords encouraged the use of a prelexical naming strategy in the shallower orthographies. Indeed, when nonwords were not included in the stimulus lists, no differences in semantic facilitation were found in naming phonologically opaque and phonologically transparent words in Persian.

Experiment 2 was designed to examine the weak version of the ODH using a semantic priming paradigm, while considering the hypothesis that the effects of orthographic depth are caused by the mere inclusion of nonwords in the stimuli lists. For this purpose semantic facilitation in naming target words was examined in pointed and unpointed Hebrew orthography, when only words were employed.

Method

Subjects. Ninety-six undergraduate students from the Hebrew University, all native speakers of Hebrew, participated in the experiment for course credit or for payment.

Stimuli and design. The stimuli were 48 target words that were paired with semantically related and semantically unrelated primes. Related targets and primes were two instances of a semantic category. In order to avoid repetition effects, two lists of stimuli were constructed. Targets presented with semantically related primes in one list were unrelated in the other list, and vice versa. Each subject was tested in one list only. There were two experimental conditions: In one condition all stimuli were pointed, and in the other they were unpointed. Forty-eight subjects were tested in each condition, 24 on each list. The targets were three- to five-letter words and had two or three syllables. Both primes and targets were unambiguous, and each could be read as a meaningful word in only one way.

Procedure and apparatus. An experimental session consisted of 16 practice trials followed by the 48 test trials. Each trial consisted of a presentation of the prime for 750 ms followed by the presentation of the target. Subjects were instructed to read the primes silently and to name the targets aloud. The exposure of the target was terminated by the subject's vocal response, and the intertrial interval was 2 s. The apparatus was identical to the one used in the naming task of Experiment 1.

Results

RTs in the different experimental conditions are presented in Table 2. Naming of related targets was faster than naming of unrelated targets in both pointed and unpointed print. However, semantic facilitation was twice as large with unpointed print than with pointed print.

The statistical significance of these effects was assessed by an ANOVA across subjects, F_1, and across stimuli, F_2, with the main factors of semantic relatedness (related, unrelated), and print type (pointed, unpointed). The effect of semantic relatedness was significant, $F_1(1, 47) = 20.9$, $MS_e = 656$, $p < 0.001$; $F_2(1, 94) = 33.2$, $MS_e = 363$, $p < 0.001$. The effect of print type was significant in the subject analysis, $F_1(1, 47) = 30.8$, $MS_e = 232$, $p < 0.001$, but not in the stimulus analysis, $F_2(1, 94) = 1.0$. More importantly, the two-way interaction was significant in both analyses, $F_1(1, 47) = 6.6$, $MS_e = 207$, $p < 0.01$; $F_2(1, 94) = 4.7$, $MS_e = 363$, $p < 0.03$. A Tukey-*a* post hoc analysis of the interaction ($p < 0.05$) revealed that the semantic facilitation was significant only with unpointed print, but not with pointed print.

Discussion

Similar to Experiment 1, naming in pointed print was found to be faster than naming in unpointed print, as revealed by the difference in RTs in the unrelated condition. However, whereas semantic relatedness accelerated naming in the related condition in unpointed print, it had a much smaller effect on accelerating naming latencies in pointed print. Thus the results of Experiment 2 suggest that semantic facilitation is stronger in the deeper than in the shallower Hebrew orthography. This outcome is in complete agreement with the findings of Frost et al. (1987) and Tabossi & Laghi (1992). Note, however, that the greater effects of semantic facilitation in pointed print than in unpointed print were obtained even though nonwords were not included in the stimulus set. These results conflict with the findings of Baluch and Besner (1991). We will refer to this in the General Discussion section.

Experiment 3

The major claim of the weak ODH is that in all orthographies both prelexical and lexical phonology are involved in naming. Thus, the use of lexical or prelexical phonology is not an all-or-none process but a quantitative continuum. The degree to which a prelexical process of assembling phonology predominates over the lexical routine depends on the costs involved in assembling phonology directly from the print. The ODH suggests that unless the costs are too high in terms of processing resources (as is usually the case in deep orthographies), the default strategy of the cognitive system is to assemble a phonologic code for lexical access, not to retrieve it from the lexicon following visual access. The following two experiments examined this aspect of the hypothesis by manipulating the processing costs for generating a prelexical phonological representation.

The manipulation of cost consisted of delaying the presentation of the vowel marks relative to the presentation of the consonant letters. In Experiment 3 subjects were presented with unambiguous letter strings that could be read as one meaningful word only (i.e., only one vowel combination created a meaningful word). The letters were followed by the vowel marks, which were superimposed on the consonants, but at different time intervals ranging from 0 ms (in fact, a regular pointed presentation) to 300 ms from the onset of consonant presentation. Subjects were instructed to make lexical decisions or to name the words as soon as possible.

The vowel marks allow the easy prelexical assembly of the word's phonology using spelling-to-phonology conversion rules. However, since the letter strings were unambiguous and could be read as a meaningful word in only one way, they could be easily named using the addressed routine, by accessing the lexicon visually. In fact, as we have shown in numerous studies, this naming strategy is characteristic of reading unpointed Hebrew (see Frost & Bentin, 1992b, for a review). The question was, therefore, whether subjects are inclined to delay their response and wait for the vowel marks that are not indispensable for either correct lexical decisions or for unequivocal pronunciation. If they are willing to wait for the vowel marks to appear then it must be because they prefer the option of prelexical assembly of phonology, just as the ODH would predict. The relative use of the assembled and addressed routines was also verified by using both high-frequency and low-frequency words in the stimulus lists. It was assumed that the more subjects rely on the vowel marks for naming using GPC conversion rules, the smaller would be the frequency effect in this task. Nonwords were introduced as well to allow a baseline assessment of the lagging costs. Note that nonwords cannot be unequivocally pronounced before the vowel marks are presented. In order to correctly pronounce them, subjects have to wait the full lag period. However, since at least some of the articulation program can be launched immediately after the consonants are presented, the absolute difference in RTs between the presentation at lag 0 and at lag 300 of nonwords would reflect the actual cost in response time for lagging the vowel marks by 300 ms. Any lag effect smaller than this difference would suggest that subject did not wait the full lag period but combined both prelexical and lexical routines to formulate their response.

Method

Subjects. Ninety-six undergraduate students from the Hebrew University, all native speakers of Hebrew, participated in the experiments for course credit or for payment. Forty-eight participated in the lexical decision task and 48 in the naming task.

Stimuli and design. The stimuli were 40 high-frequency words (mean frequency 5.0 on the previously described 1–7 scale), 40 low-frequency words (mean frequency 3.6), and 80 nonwords. All words were unambiguous; their pronunciation was unequivocal, that is, they could be read as a meaningful word in only one way. Nonwords were created by altering one letter of a real word, and could not be read as a meaningful word with any vowel configuration. All stimuli were three to five letters long, and contained two syllables with four to six phonemes. The average number of letters and phonemes was similar for the three types of stimuli.

The words were presented to the subjects for lexical decision or naming. Forty-eight different subjects were tested in each task with the same stimuli. The stimuli were presented in four lag conditions: 0, 100, 200, and 300 ms. Each lag was defined by the stimulus onset asynchrony (SOA) between the presentation of the consonants and the vowel marks. Thus, at lag 0 the consonants and the vowel marks were presented simultaneously, at lag 100 the consonants were presented first and the vowel marks were superimposed 100 ms later, and so on. Four lists of words were formed: Each list contained 160 stimuli that were composed of 10 high-frequency words, 10 low-frequency words, and 20 nonwords in each of the four lag conditions. The stimuli were rotated across lists by a Latin square design so that words that appeared in one lag in one list appeared in another lag in another list, and so forth. The purpose of this rotation was to test each subject in all lagging conditions while avoiding repetitions within a list. The subjects were randomly assigned to each list and to each experimental condition (lexical decision or naming).

Procedure and apparatus. The procedure and apparatus were identical to those used in the previous experiments. The only difference was that the letters and the vowel marks appeared with the different SOAs. The clock for measuring response times was initiated on each trial with the presentation of the letters, regardless of vowel marks. The subjects were informed of the SOA manipulation but were requested to communicate their lexical decisions or vocal responses as soon as possible, that is, without necessarily waiting for the vowel marks to appear. Each session started with 16 practice trials. The 160 test trials were presented in one block.

Results

Mean RTs for high-frequency words, low-frequency words, and nonwords in the different lag conditions for both the

Table 3
Lexical Decision and Naming Reaction Times (RTs; in Milliseconds) and Percent Errors for High-Frequency Words, Low-Frequency Words, and Nonwords, When Vowel Marks Appear at Different Lags After Letter Presentation

	Lexical decision					Naming				
Lag condition	0-ms lag	100-ms lag	200-ms lag	300-ms lag	Lag effect	0-ms lag	100-ms lag	200-ms lag	300-ms lag	Lag effect
High-frequency words										
RT	546	551	560	571	25	587	608	610	648	62
% error	6	6	7	6		4	3	4	3	
Low-frequency words										
RT	626	642	644	663	37	598	624	648	678	80
% error	12	10	11	10		5	3	4	5	
Frequency effect	80	91	84	92		11	16	38	30	
Nonwords										
RT	641	644	684	710	69	655	700	736	799	144
% error	9	8	8	9		5	7	5	7	

Note. Words are unambiguous.

lexical decision and the naming tasks are presented in Table 3. Although the response pattern at each of the different lags is important, for the purpose of simplicity the *lag effect* specified in Table 3 reflects the difference between the simultaneous presentation (lag 0) and the longest SOA (lag 300).

The lagging of the vowel information had relatively little effect in the lexical decision task. The presentation of vowels marks 300 ms after the letters delayed subjects' responses by only 25 ms for high-frequency words, and 37 ms for low-frequency words. The lagging of vowels had a somewhat greater effect on the nonwords. Across all lags, the frequency effect was stable, about 85 ms on the average. In contrast to lexical decisions, the effect of lagging the vowel information had a much greater influence on naming. However, the frequency effect was very small at lag 0 and 100.

The statistical significance of these differences was assessed in a three-way ANOVA with the factors of task (lexical decision, naming), stimulus type (high-frequency, low-frequency, nonwords), and lag (0, 100, 200, 300), across subjects and across stimuli. The main effect of task was significant, $F_1(1, 94) = 4.2$, $MS_e = 70{,}811$, $p < 0.04$; $F_2(1, 157) = 35$, $MS_e = 8{,}320$, $p < 0.001$, as was the main effect of stimulus type, $F_1(2, 188) = 252$, $MS_e = 4{,}914$, $p < 0.001$; $F_2(2, 157) = 106$, $MS_e = 13{,}354$, $p < 0.001$, and the main effect of lag, $F_1(3, 282) = 98$, $MS_e = 2{,}495$, $p < 0.001$; $F_2(3, 471) = 94$, $MS_e = 2{,}587$, $p < 0.001$. Task interacted with stimulus type, $F_1(2, 188) = 23.1$, $MS_e = 4{,}914$, $p < 0.001$; $F_2(2, 157) = 13$, $MS_e = 8{,}320$, $p < 0.001$, and with lag, $F_1(3, 282) = 13.4$, $MS_e = 2{,}495$, $p < 0.001$; $F_2(3, 471) = 22$, $MS_e = 1{,}387$, $p < 0.001$. Lag interacted with stimulus type, $F_1(6, 564) = 9.3$, $MS_e = 2{,}076$, $p < 0.001$; $F_2(6, 471) = 9$, $MS_e = 2{,}587$, $p < 0.001$. The three-way interaction did not reach significance in the subject analysis ($F_1 = 1.3$) but was marginally significant in the stimulus analysis, $F_2(6, 471) = 2.1$, $MS_e = 1{,}387$, $p < 0.05$. A Tukey-*a* post hoc test revealed that the frequency effect in naming was significant only at the longer lags (200, 300 ms SOA), and not in the shorter lags (0, 100 ms SOA), whereas in lexical decisions the frequency effect was significant at all lags ($p < 0.05$).

Discussion

The results of Experiment 3 suggest that the effective cost of delaying vowel marks in lexical decisions in Hebrew is relatively low. A lag of 300 ms in vowel marks presentation resulted in 25 ms difference in response time for high-frequency words and 37 ms for low-frequency words. This outcome suggests that subjects were not inclined to wait for the vowel marks to formulate their lexical decisions; rather, their responses were based on the recognition of the letter cluster. This interpretation converges with previous studies that showed that lexical decisions in Hebrew are not based on a detailed phonological analysis of the printed word, but rely on a fast judgment of the printed word's orthographic familiarity based on visual access to the lexicon (Bentin & Frost, 1987; Frost & Bentin, 1992a). The slightly higher cost of lagging the vowel marks with low-frequency words and the even higher one for nonwords proposes that stimulus familiarity played a role in the decision strategy. This suggests that for words that were less familiar, or for nonwords, subjects were more conservative in their decisions and were inclined to wait longer for the vowel marks, for the possible purpose of obtaining a prelexical phonological code as well. In addition to the lag effect, a strong frequency effect was obtained at all lags. This provides further confirmation of lexical involvement in the task, regardless of the vowel mark presentation.

A very different pattern of results emerged in the naming task. The effective cost of delaying the vowel marks in naming was much higher. The lag effect obtained in naming words was about 70 ms on the average, twice as large as the effect found for lexical decisions. Thus, although the phonologic structure of the unambiguous words could be unequivocally retrieved from the lexicon following visual access (addressed phonology), subjects were more inclined to wait for the vowels to appear in the naming task than in the lexical decision task, presumably in order to generate a prelexical phonologic code. The lag effect for words suggests that subjects combined both prelexical and lexical routines to name words, but the relative use of the prelexical and lexical routines varied as a function of the delay in vowel mark presentation. This lag effect should be first compared to the effect obtained for naming nonwords. Because they cannot be named correctly without the vowel marks, the lag effect for nonwords reflects the overall cost in response time due to a 300-ms delay of vowel mark presentation. This cost is smaller than the lag itself because the articulation program can be initiated as the letters appear, previous to the vowel mark presentation. The results suggest that the cost of lagging the vowel marks by 300 ms is about 150 ms in response time. Thus, the adoption of a pure prelexical strategy of naming words should have resulted in a similar lag effect. The results suggest that this was not the strategy employed in naming words: The lag effect for words was only half the effect obtained for nonwords. However, the lag effect for naming words should also be compared to the lag effect obtained in the lexical decision task. Note that, as in the lexical decision task, subjects did not need the vowel marks (and a prelexical phonologic code) to name the words correctly. Nevertheless, in contrast to lexical decision, they preferred to wait longer for the vowel information. It could be argued that the introduction of nonwords introduced the prelexical strategy in naming. However, since the lag effect for words was much smaller than the lag effect for nonwords, it suggests that a combined use of the assembled and addressed routine was used in pronunciation.

Another possible interpretation could be suggested, however, to account for the lag effect in naming. Because in the naming task subjects are required to produce the correct pronunciation of the printed word, they might have adopted a strategy of waiting for the vowels in order to verify the phonologic structure of the printed word which they generated lexically. By this interpretation, phonology was lexically addressed but verified at a second stage against the delayed vowel information to confirm the lexically retrieved pronunciation. The verification interpretation would regard the difference in naming words and nonwords in this paradigm as the difference between having words verified by the subsequently presented vowels, which is short, and having to construct a pronunciation from the vowel information, which is longer.

Although this interpretation is plausible, it is not entirely supported by the effect of word frequency on response latencies. The suggestion that the combined use of prelexical and lexical phonology varied as a function of the cost of generating a prelexical phonological code is reinforced by examining the frequency effect in naming. In contrast to lexical decision, the frequency effect in naming was overall much smaller, especially at the shorter SOAs. At the 0 ms SOA the frequency effect decreased from 80 ms in lexical decision to 11 in naming. This supports the conclusion that naming with the simultaneous presentation of vowels was mainly prelexical and scarcely involved the mental lexicon. The longer the SOA, the larger the cost of generating a prelexical phonologic code and, consequently, the greater the use of addressed lexical phonology. This is reflected in the increase in the frequency effect at the longer SOAs (38 and 30 ms for 200 and 300 ms SOA, respectively). This pattern stands in sharp contrast to the lexical decision task, which yielded very similar frequency effects at all lags.[2]

Experiment 4

The aim of Experiment 4 was to examine the effect of lagging the vowel marks when phonologically ambiguous words (heterophonic homographs) are presented for lexical decision or naming. In contrast to unambiguous words, the correct phonological structure of Hebrew heterophonic homographs can be determined unequivocally only by referring to the vowel marks, which specify the correct phonological alternative and consequently the correct meaning. Thus, if the analysis provided in the previous experiment concerning the cost of lagging the vowel marks is correct, the effect of presenting ambiguous words on naming should be similar to the effect of presenting nonwords. In both cases, subjects would have to rely on the vowel marks for generating a phonological representation necessary for pronunciation. In contrast, lagging the vowel marks of ambiguous words should affect lexical decisions to a much lesser extent. This is because lexical decisions for ambiguous words have been previously shown to be based on the abstract orthographic structure, and occur prior to the process of phonological disambiguation (Bentin & Frost, 1987; Frost & Bentin, 1992a).

In Experiment 4 subjects were presented with letter strings that could be read as two meaningful words, depending on the vowel configuration assigned to the letters. Nonwords were presented as well. The vowel marks were superimposed on the letters at different lags, the same as those employed in Experiment 3. The relative use of orthographic and phonologic coding in the two tasks was again assessed by measuring the effect of lagging the vowel information on lexical decision and naming.

Method

Subjects. One hundred and sixty undergraduate students from the Hebrew University, all native speakers of Hebrew, participated in the experiment for course credit or for payment. Eighty participated in the lexical decision task and 80 in the naming task. None of the subjects had participated in the previous experiment.

Stimuli and design. The words were 40 ambiguous consonant strings each of which represented both a high-frequency and a low-frequency word. The two phonological alternatives were mostly nouns or adjectives that were not semantically or morphologically related. The procedure for assessing the subjective frequencies of the words was similar to the one employed in the previous experiments: Fifty undergraduate students were presented with lists that contained the pointed disambiguated words related to the 40 ambiguous letter strings, and rated the frequency of each word on a 7-point scale. The rated frequencies were averaged across all 50 judges. Each of the 40 homographs that were selected for this study represented two words that differed in their rated frequency by at least 1 point on that scale. As in the previous experiments, the nonwords were constructed by altering one or two letters of meaningful words. The design was similar to that of Experiment 3. However, in order to avoid repetition of the same letter string with different vowel marks, eight lists of words were presented to the subjects instead of four (hence the larger number of subjects). Each list contained only one form (the dominant or the subordinate) of each homograph, at one of the possible four lags, so that each subject was presented with 40 words and 40 nonwords in a list. The stimuli were rotated across lists by a Latin square design, and consequently each letter string was presented with both vowel mark configurations at all possible lags.

Procedure and apparatus. The procedure and apparatus were identical to those of Experiment 3. Each session started with 16 practice trials, followed by the 80 test trials, which were presented in one block.

Results

Mean RTs for the dominant alternatives, the subordinate alternatives and the nonwords in the different lag conditions for both the lexical decision and the naming tasks are presented in Table 4. As in Experiment 3, the effect of lagging the vowel information had little influence on lexical decision latencies. In fact, the use of ambiguous words reduced the difference between the simultaneous presentation of vowels and their presentation 300 ms after the letters to 21 ms for words on the average, and to only 6 ms for nonwords. A different pattern emerged in the naming task. The effects of lagging the vowel marks on RTs were twice as large as the effects found for unambiguous words in Experiment 3, where there was only one meaningful pronunciation. In fact, the lag effect on ambiguous words was virtually identical with the lag effect on nonwords.

The statistical significance of these differences was assessed in a three-way ANOVA with the factors of task (lexical decision, naming), stimulus type (high-frequency, low-frequency, nonwords), and lag (0, 100, 200, 300), across subjects and across stimuli. The main effect of task was significant, $F_1(1, 158) = 39$, $MS_e = 11{,}428$, $p < 0.001$; $F_2(1, 117) = 314$, $MS_e = 7{,}379$, $p < 0.001$, as was the main effect of stimulus type, $F_1(2, 316) = 42$, $MS_e = 7{,}541$, $p < 0.001$; $F_2(2, 117) = 10.5$, $MS_e = 11{,}737$, $p < 0.001$, and the main effect of lag, $F_1(3, 474) = 69$, $MS_e = 8{,}459$, $p < 0.001$; $F_2(3, 351) = 113$, $MS_e = 2{,}528$, $p < 0.001$. Task interacted with stimulus type, $F_1(2, 316) = 6.6$, $MS_e = 7{,}541$, $p < 0.001$; $F_2(2, 117) = 5.8$, $MS_e = 7{,}379$, $p < 0.001$, and with lag, $F_1(3, 474) = 46$, $MS_e = 8{,}459$, $p < 0.001$;

[2] Note that the effect of delaying vowels on naming latencies does not linearly decrease with lag, as should be predicted by the increase of frequency effect. In order to obtain a more ordered relationship more lag conditions should have been used.

Table 4
Lexical Decision and Naming Reaction Times (RTs; in Milliseconds) and Percent Errors for High-Frequency Words, Low-Frequency Words, and Nonwords When Vowel Marks Appear at Different Lags After Letter Presentation

	Lexical decision					Naming				
Lag condition	0-ms lag	100-ms lag	200-ms lag	300-ms lag	Lag effect	0-ms lag	100-ms lag	200-ms lag	300-ms lag	Lag effect
Dominant										
RT	585	608	608	611	26	619	650	692	763	142
% error	4	5	3	3		3	2	4	3	
Subordinate										
RT	611	620	626	627	16	641	699	739	790	150
% error	7	5	4	2		5	4	6	4	
Nonwords										
RT	624	629	635	630	6	677	713	755	828	151
% error	9	9	10	10		5	4	8	7	

Note. Words are ambiguous.

$F_2(3, 351) = 76, MS_e = 2{,}616, p < 0.001$. Lag did not interact with stimulus type ($F_1, F_2 < 1.0$). The three-way interaction did not reach significance ($F_1 = 1.3, F_2 = 1.4$).

Discussion

The results of Experiment 4 suggest that the cost of delaying the vowel marks for phonologically ambiguous letter strings in the lexical decision task was very low. This outcome supports the conclusions put forward by Frost & Bentin (1992a), 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.

The longest delays of response times due to the lagging of vowel information occurred in the naming task. This was indeed expected. Because the correct pronunciation of phonologically ambiguous 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. This baseline confirms the previous assessment, which was based on the responses to nonwords in Experiment 3, and suggests that, overall, 300 ms in delaying the vowel marks cost 150 ms in response time for articulation if the vowels are necessary for correct pronunciation.

Note that, in contrast to the unambiguous words of Experiment 3, the difference in RTs between dominant and subordinate alternatives of ambiguous words cannot reveal the extent of lexical involvement. First, this difference cannot be accurately labeled as a frequency effect. The two phonological alternatives of each homograph differed only in their dominance, and thus could have been both frequent or both nonfrequent. Moreover, there is a qualitative difference between frequency effects that arises from lexical search and the dominance effect that results from the conflict between two phonological alternatives of heterophonic homographs. Thus, the slower RTs of subordinate alternatives, at least in the naming task, were probably due not to a longer lexical search for low-frequency words, but to a change in the articulation program. If subjects first considered pronouncing the dominant alternative after the ambiguous consonants were presented, the later appearance of the vowel marks that specified the subordinate alternative would have caused a change in their articulation plan, resulting in slower RTs.

General Discussion

The present study investigated the relative use of assembled and addressed phonology in naming unpointed and pointed printed Hebrew words. Experiment 1 demonstrated that the lexical status of the stimulus had greater effect in unpointed than in pointed print. Experiment 2 confirmed that semantic priming facilitated naming to a lesser extent in the shallow pointed orthography than in the deeper unpointed orthography, even though nonwords were not included in the stimulus list. Experiments 3 and 4 examined the effect of delaying the vowel mark presentation on lexical decision and naming in order to assess their contribution and importance in the two tasks. Because the vowel marks allow fast conversion of the graphemic structure into a phonologic representation using prelexical conversion rules, their delay constitutes an experimental manipulation that reflects the cost of assembling phonology from print. The two experiments showed that, although both naming and lexical decision could be performed without considering the vowel marks, subjects were inclined to use them to a greater extent in the naming task when the cost in response delay was low.

These results provide strong support for the weaker version of the ODH. The disagreement between the alternative view and the ODH revolves around the extent of using assembled phonology in shallow orthographies. It is more or less unanimously accepted that in deep orthographies readers prefer to use the addressed routine in naming. This is because the opacity of the relationship between orthographic structure and phonologic form, which is characteristic of deep orthographies, prevents readers from assembling a prelexical phonological representation through the use of simple GPC rules. Thus, the major debate concerning the validity of the ODH often takes place on the territory of shallow orthographies, in order to show their extensive use of addressed phonology in naming. What lies behind the alternative view, therefore, is the assumption (even axiom) that the use of the addressed routine for naming constitutes the least cognitive effort for any reader in any alphabetic orthography.

The advantage of examining the validity of the ODH by investigating reading in pointed and unpointed Hebrew is therefore multiple. First, it is well established that Hebrew readers are used to accessing the lexicon by recognizing the word's orthographic structure. The phonologic information needed for pronunciation is then addressed from the lexicon (Frost & Bentin, 1992b). The question of interest, then, is: What reading strategies are adopted by Hebrew readers when they are exposed to a shallower orthography? Do they adopt a prelexical strategy even though it is not the natural strategy for processing most Hebrew reading material? A demonstration of the extensive use of the assembled routine in pointed Hebrew therefore provides strong support for the ODH. If readers of Hebrew prefer the use of the assembled routine, surely habitual readers of shallower orthographies would have a similar preference.

The second advantage in using the two orthographies of Hebrew is that it allows the manipulation of a within-language, between-orthography design. This design has a methodological advantage over studies that compare different languages. The interpretation of differences in reading performance between two languages as reflecting subjects' use of pre- versus post-lexical phonology can be criticized on methodological grounds. The correspondence between orthography and phonology is only one dimension on which two languages differ. English and Serbo-Croatian, for example, differ in grammatical structure and in the size and organization of the lexicon. These confounding factors, it can be argued, may also affect subjects' performance. The comparison of pointed and unpointed orthography in one language, Hebrew, allows these pitfalls to be circumvented.

Taken together, the four experiments suggest that the presentation of vowel marks in Hebrew encourages the reader to generate a prelexical phonologic representation for naming. The use of the assembled routine was detected by examining both frequency and semantic priming effects in naming. Experiment 3 provides an important insight concerning the preference for prelexical phonology. When the vowels appeared simultaneously with the consonants, the frequency effect in naming was small and nonsignificant, again suggesting minimal lexical involvement. Thus the results of this condition replicate the findings of Experiment 1.

Two methodological factors should be considered in interpreting the results of Experiments 3 and 4. The first relates to the experimental demand characteristics of the lagged pointed presentation. It could be argued that this unnatural presentation of printed information encouraged subjects to wait for the vowels to appear and consequently to use them. In fact, why not adopt a strategy of waiting for all possible information to be provided? Although this could be a reasonable solution for efficient performance in these experiments, the results of the lexical decision task make it very unlikely that this simple strategy was adopted by our subjects. In this task subjects were not inclined to wait for the vowel marks. This result was most conspicuous in Experiment 4, in which the lag effect was minimal. This outcome suggests that the lagged presentation did not induce a uniform strategy of vowel mark processing, but that subjects adopted a flexible strategy characterized by a gradual pattern of relying more and more on the vowel marks (prelexical phonology) as a function of the task and of the ambiguity of the stimuli.

The differential effect of lag on ambiguous and unambiguous words in the two tasks suggests that both the assembled and the addressed routines were used for generating phonology from print. On one hand subjects used explicit vowel information employing prelexical transformation rules. This is reflected in the greater effect of lag on naming relative to lexical decision latencies, and in the smaller frequency effect of Experiment 3 at the shorter SOAs. On the other hand, it is clear that the phonologic structure of unambiguous words was generated using the addressed routine as well. This is reflected in the differential effect of lagging the vowel information on naming ambiguous and unambiguous words: There were smaller effects of lag on naming unambiguous than ambiguous words. This confirms that subjects did not wait for the vowel marks in order to pronounce the unambiguous words, as long as they waited in order to pronounce the ambiguous words. The flexibility in using the two routines for naming unambiguous words was affected, however, by the "cost" of the vowel information. When no cost was involved in obtaining the vowel information (simultaneous presentation), the prelexical routine was preferred, as reflected by the small frequency effect. In contrast, when the use of vowel information involved a higher cost, given the delayed presentation of the vowel marks, a gradually greater reliance on the addressed routine was observed. This is well reflected by the larger frequency effect at the longer lags. This pattern stands in sharp contrast to the lexical decision task, in which the frequency effect was stable and very similar across lags.

The second methodological issue to be considered in interpreting the results of Experiments 3 and 4 is the presence of nonwords in the experiments. One factor that has been recently proposed to account for the conflicting results concerning the effect of orthographic depth is the inclusion of nonwords in the stimulus list (Baluch & Besner, 1991). In their study, Baluch and Besner presented native speakers of Persian with opaque and transparent Persian words and showed that differences in semantic facilitation in the naming task appeared only when nonwords were included in the stimulus list. When the nonwords were omitted, no differences in semantic facilitation were found. Baluch and Besner concluded that the inclusion of nonwords in the list encourages subjects to adopt a prelexical strategy of generating phonology from print, because the phonologic structure of nonwords cannot be lexically addressed but only prelexically assembled.

The results of Experiments 3 and 4 do not support the view that the nonwords induced a pure prelexical strategy. If this were so, the effects of lag would have been similar for words and for nonwords. Subjects would have waited for the vowels of every stimulus to appear and the lag effect for unambiguous words, ambiguous words, and nonwords would have been similar, about 150 ms. This clearly was not the outcome we obtained. Subjects waited the full 150 ms to pronounce the nonwords and the ambiguous words but waited only half as much time to pronounce the unambiguous words. This confirms a mixed strategy in reading.

However, the argument proposed by Baluch and Besner (1991) deserves serious consideration. Not only is its logic compelling, but also the effect of nonwords on reading strategies is well documented in several studies. The crux of the debate is, however, whether this argument can account for the observed effects of orthographic depth found in the various studies described above (e.g., Frost et al., 1987; Katz & Feldman, 1983). The evidence for that claim seems to be much less compelling. There is no argument that nonwords induce a prelexical strategy of reading in all orthographies (e.g., Hawkins, Reicher, & Rogers, 1976; and see McCusker, Hillinger, & Bias, 1981, for a review). However, note that the weak ODH proposes that whatever the effect of nonword inclusion is, it would be different in deep and in shallow orthographies. Thus, evidence for or against the weak ODH could only be supported by studies directly examining the differential effect of nonwords in various orthographies. Such a design was indeed employed by Baluch & Besner, but their conclusions hinge on the nonrejection of the null hypothesis. In contrast to their results, several studies have provided clear evidence supporting the weak ODH. For example, Frost et al. (1987) showed that the ratio of nonwords had a dramatically different effect on naming in Hebrew, in English, and in Serbo-Croatian. Different effects of nonwords inclusion on semantic facilitation in naming in the deep English and the shallow Italian, were also reported by Tabossi & Laghi (1992).

The results of Experiment 2 also stand in sharp contrast to Baluch and Besner's (1991) conclusions. In Experiment 2 different semantic priming effects were found between pointed and unpointed Hebrew, even though nonwords were not included in the stimulus list. How can this difference be accounted for? A possible explanation for this discrepancy could be related to the strength of the experimental manipulation employed in the two studies. Baluch and Besner used opaque and transparent words within the unpointed-deep Persian writing system. The phonological transparency of their words was due to the inclusions of letters that convey vowels. However, because these letters can also convey consonants in a different context, they may have introduced some ambiguity in the print that is characteristic of deep orthographies, hereby encouraging the use of the addressed routine. In contrast, the experimental manipulation of using pointed and unpointed Hebrew print is much stronger. Hence, differential effects of semantic facilitation in naming emerged in Hebrew, providing strong support for the weak ODH.

The debate concerning the ODH, however, cannot simply revolve around the interpretation of various findings without adopting a theoretical framework for reading in general. Interestingly, in contrasting the ODH with the alternative view, one might find very similar definitions that capture these conflicting approaches. Proponents of the alternative view would argue that, regardless of the characteristics of their orthography, readers in different languages seem to adopt remarkably similar mechanisms in reading (e.g., Besner & Smith, 1992; Seidenberg, 1992). Thus, the alternative view attempts to offer a universal mechanism that portrays a vast communality in the reading process in different languages. Surprisingly, proponents of the ODH take a very similar approach. They suggest a basic mechanism for processing print in all languages, which is finely tuned to the particular structure of every language (Carello et al., 1992). The major discussion is, therefore, what exactly this mechanism is.

The basic assumption of the ODH concerns the role of phonology in reading. It postulates as a basic tenet that all writing systems are phonological in nature and their primary aim is to convey phonologic structures (i.e., words) regardless of the graphemic structure adopted by each system (see De Francis, 1989; Mattingly, 1992, for a discussion). Thus, the extraction of phonologic information from print is the primary goal of the reader, whether skilled or beginner. It is the emphasis upon the role of phonology in the reading process that bears upon the importance of prelexical phonology in print processing. The results of the present study furnish additional support for an increasingly wide corpus of research that provides evidence confirming the role of prelexical phonology in reading. This evidence comes not only from shallow orthographies like Serbo-Croatian (e.g., Feldman & Turvey, 1983; Lukatela & Turvey, 1990), but also from deeper orthographies like English, using a backward masking paradigm (e.g., Perfetti et al., 1988) or a semantic categorization task with pseudohomophonic foils (Van Orden, 1987; Van Orden, Johnston, & Hale, 1988). Recently, Frost and Bentin (1992a) showed that phonologic analysis of printed heterophonic homographs in the even deeper unpointed Hebrew orthography precedes semantic disambiguation. In another study, Frost and Kampf (1993) showed that the two phonologic alternatives of Hebrew heterophonic homographs are automatically activated following the presentation of the ambiguous letter string.

The results of the present study converge with these findings. They provide an opportunity to examine the ODH and the alternative view not in the linguistic environment of shallow orthographies, but of deep orthographies. If prelexical phonology plays a significant role in the reading of pointed Hebrew by readers who are trained to use mainly the addressed routine for phonological analysis, then the plausible conclusion is that, in any orthography, assembled phonology plays a much greater role in reading than the alternative view would assume.

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