

# New Evidence for Phonological Processing During Visual Word Recognition: The Case of Arabic

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Lexical decision and naming were examined with words and pseudowords in literary Arabic and with transliterations of words in a Palestinian dialect that has no written form. Although the transliterations were visually unfamiliar, they were not easily rejected in lexical decision, and they were more slowly accepted in phonologically based lexical decision. Naming transliterations of spoken words was slower than naming of literary words and pseudowords. Apparently, phonological computation is mandatory for both lexical decision and naming. A large frequency effect in both lexical decision and naming suggests that addressed phonology is an option for familiar orthographic patterns. The frequency effect on processing transliterations indicated that lexical phonology is involved with prelexical phonological computation even if addressed phonology is not possible. These data support a combination between a cascade-type process, in which partial products of the grapheme-to-phoneme translation activate phonological units in the lexicon, and an interactive model, in which the activated lexical units feed back, shaping the prelexical phonological computation process.

In several models of visual word recognition, researchers have proposed that fluent readers do not use the phonological information conveyed by printed words until after their meaning has been identified (e.g., Banks, Oka, & Shugarman, 1981; Jared & Seidenberg, 1991; Paap, Newsome, McDonald, & Schvaneveldt, 1982; Saffran & Marin, 1977). Accordingly, the term *postlexical phonology* has been used to denote the idea that the phonological lexicon is accessed through a top-down process initiated by the activation of a semantic node (Besner, Davis, & Daniels, 1981; Foss & Blank, 1980; Patterson & Coltheart, 1987). In their extreme forms, such models assume that, although orthographic units may automatically activate phonological units in parallel with the activation of meaning, lexical access and the recognition of printed words may be mediated exclusively by orthographic word-unit attractors in a parallel distributed network (if one takes a connectionist approach, e.g., Hinton & Shallice, 1991; Seidenberg & McClelland, 1989) or by a visual logogen system (if one prefers a more traditional view, e.g., Morton, 1969; Morton & Patterson, 1980).

Much of the empirical evidence supporting the orthographic-semantic models of word recognition comes from the neuropsychological laboratory. For example, patients with a form of

acquired alexia labeled *deep dyslexia* apparently cannot use grapheme-to-phoneme translation, yet they are able to identify printed high-frequency words (Patterson, 1981). Furthermore, the reading errors made by such patients are predominantly semantic paralexias and visual confusions (for a review, see Coltheart, 1980). These data were therefore interpreted as reflecting identification of printed words by their whole-word visual-orthographic (rather than phonologic) structure. The propriety of generalizing these data to normal reading is questionable, but additional support for the orthographic-semantic view can also be found in studies of normal word recognition. For example, in Hebrew (as in Arabic), letters represent mostly consonants, whereas vowels may be represented in print by a set of diacritical marks (points). These points are frequently not printed, and under these circumstances, isolated words are phonologically and semantically ambiguous. Nevertheless, it has been found that in both Hebrew (Bentin, Bargai, & Katz, 1984) and Arabic (Roman & Pavard, 1987) the addition of phonological disambiguating vowel points inhibits (rather than facilitates) lexical decision. On the basis of such results, it has been suggested that, at least in Hebrew, correct lexical decisions may be initiated on the basis of orthographic codes, before a particular phonological unit has been accessed (Bentin & Frost, 1987). In English, a distinction has been made between frequent and infrequent words. Whereas it is usually accepted that phonological processing is required to identify infrequent words, frequent words are presumed to be identified on the basis of their familiar orthographic pattern (Seidenberg, 1985b).

Advocates of phonological mediation, on the other hand, claim that access to semantic memory is necessarily mediated by phonology (e.g., Frost, 1995; Liberman, 1992; Liberman & Liberman, 1990). In a "weaker" form of the phonological-mediation view, it is suggested that although the phonologic structure may not necessarily be a vehicle for semantic access, it is automatically activated and integrated in the process of

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word recognition (Van Orden, 1991; Van Orden, Pennington, & Stone, 1990). Such models assume that phonological entries in the lexicon can be either accessed by assembling the phonological structures at a prelexical level or addressed directly from print, using whole-word orthographic patterns. The problem of orthographic-phonemic irregularity is thus solved by acceptance of the concept of addressed phonology. Indeed, cross-language comparisons indicate that addressed phonology is the preferred strategy for naming printed words in deep orthographies (Frost, Katz, & Bentin, 1987; but see Frost, 1995).

Given that all of the above strategies are in principle possible, the focus of most contemporary studies of word recognition has shifted from attempting to determine which of the above theories is better supported by empirical evidence, to understanding how the different kinds of information provided by printed words interact during word recognition (e.g., Taraban & McClelland, 1987). Along these lines, one aim of the present study was to examine whether the reader has the option of ignoring the phonological information provided by printed stimuli when such information may interfere with efficient performance. To achieve this aim, we took advantage of a specific property found in the Arabic language in which the spoken dialects are not used in print. A second aim of the present study was to examine word-recognition processes in a language that has some unique features and has not been extensively investigated. Comparisons of reading Arabic and French suggest that word-recognition processes may be slightly different in these two languages, possibly because of the additional morphologic complexity of Arabic relative to French (Courrieu & Do, 1987; Farid & Grainger, in press).

The Arabic language has two major forms. One, literary Arabic, is universally used throughout the Arab world in all written texts from the *Koran* to modern newspapers. Literary Arabic is not, however, used in mundane speech communication. For ordinary speech, there are spoken dialects that differ across different Arab countries (and often across different regions within one country). These dialects are the mother tongue of the great majority of native speakers of Arabic, whereas the literary form is first learned in school. Although a subset of words are similarly pronounced and have the same meaning in both languages, literary and spoken Arabic are phonologically different. In addition to their having different lexica, there are phonological structures that may appear in only one of the two forms. For example, none of the literary words may start with a sequence of two consonants or with a consonant and a *schwa* (the neutral vowel), whereas many of the spoken words do. In addition, there are vowels that are pronounced differently in each language. For example, the vowels /o/ and /ε/ are used only in spoken Arabic; in literary Arabic, they are pronounced /au/ or /u/ and /æ/ or /i/, depending on the phonetic context.

The orthography of literary Arabic is visually complex. Consonants are represented by letters and frequently include diacritic marks. Vowels are usually represented by diacritic marks, although, as in other Semitic languages, some vowels are also represented by letters. Thus, as in Hebrew, if all the diacritics are presented, Arabic orthography is phonologically

transparent. However, if the vowel dots are missing, the print becomes phonologically opaque, at least to some extent. Printed material in Arabic usually includes all consonantal diacritic marks but includes only those vowels that are necessary for unequivocal reading as meaningful words (see examples in Table 1).

Because letter-to-phoneme translation is regular in Arabic orthography, it is possible to present spoken words in a printed form by using transliterations based on phoneme-to-letter transformations. Such an orthographic pattern would be very unfamiliar to readers of Arabic, but if they reverse the translation process (i.e., if they use grapheme-to-phoneme transformations), the resulting assembled phonological unit should match a phonological lexical entry.<sup>1</sup> The effect of presenting such stimuli in a lexical-decision task should, therefore, depend on the nature of the word-recognition process. If lexical decision may be based solely on the orthographic pattern, unless participants are specifically instructed to accept all stimuli that sound like words, transliterated spoken words should be processed as very unfamiliar (or illegal) nonwords. That is, they should be rejected very fast—faster than phonologically and orthographically legal nonwords (pseudowords). However, if in lexical decision, participants process the phonological information conveyed by the print, the transliterations should pose a particular problem. On the one hand, they are unfamiliar orthographic patterns, but on the other hand, they sound like real words, albeit in spoken and not in literary Arabic. Thus, these specific stimuli may have an effect similar to the pseudohomophone effect described in English—that is, they should be rejected more slowly than pseudowords are (Coltheart, Davelaar, Jonasson, & Besner, 1977; Gough & Cosky, 1977; Rubenstein, Lewis, & Rubenstein, 1971; for similar effects in Hebrew, see Bentin et al., 1984, Experiment 2). Such a delay could be explained by assuming that the phonological information extracted from these letter strings activates a lexical entry and that rejection is based on a postlexical orthographic check (e.g., Dennis, Besner, & Davelaar, 1985), or it could be explained by assuming that phonological and orthographic information are pooled in a prelexical logogen system and that the partial activation initiated by the matching phonology postpones *no* decisions (e.g., Coltheart et al., 1977).<sup>2</sup>

Predictions about naming transliterations of spoken Arabic words were also theory dependent. There is ample evidence that words are named faster than nonwords. This difference has traditionally been explained by assuming that words may access the lexicon “directly” by using whole-word orthographic

<sup>1</sup> According to our conceptualization, the lexicon is a subsystem in semantic memory that initially stores phonological information about words. With practice, orthographic information may be added to some of the lexical entries. This lexicon is the database used for both word recognition and word production.

<sup>2</sup> Alternative explanations of the pseudohomophone effect were based on the orthographic similarity between the pseudohomophone and the related real word (e.g., Taft, 1982). Such explanations, however, are irrelevant to the present study in which the transliterations were not pseudohomophones of words in literary Arabic and, therefore, did not bear any specific orthographic similarity to written words.

Table 1  
*Examples of Printed Words in Literary Arabic and Transliteration of Words in Spoken Arabic*

| Meaning    | Spoken Arabic |           | Pronunciation | Literary Arabic |           | Pronunciation |
|------------|---------------|-----------|---------------|-----------------|-----------|---------------|
|            | Pointed       | Unpointed |               | Pointed         | Unpointed |               |
| good       | برنجي         | برنجي     | brenji        | جيد             | جيد       | jaied         |
| coffee pot | بريق          | بريق      | briecck       | ابريق           | ابريق     | ibriecck      |

codes, thereby immediately accessing whole-word phonological information. In contrast, the pronunciation of nonwords must be based on a longer and less efficient process of prelexical phonological assembling (e.g., Coltheart, Besner, Jonasson, & Davelaar, 1979; Frederiksen & Kroll, 1976; Seidenberg, Waters, Barnes, & Tanenhaus, 1984).<sup>3</sup> Conforming to such a theory, because the orthographic pattern of the transliterations was (at least) as unfamiliar as the orthographic pattern of the nonwords, transliterations should have been named as fast as pseudowords, and both should have been named more slowly than literary words were. On the other hand, more recent theories and data suggest that lexical information may support prelexical phonological assembling in naming (e.g., Besner & Smith, 1992; Carello, Turvey, & Lukatela, 1992, 1994; Frost, 1995). For example, there is evidence that pseudohomophones are named faster than orthographically similar nonhomophonic nonwords are (McCann & Besner, 1987). Accordingly, transliterations should be named faster than pseudowords are.

In three experiments, we examined the processing of words in literary Arabic, legal nonwords (pseudowords) produced by substituting letters in literary Arabic words, and orthographically presented spoken words (transliterations) formed by using Arabic letters to stand for their associated phonemes.

## General Method

### Participants

The participants were 60 high school seniors (30 boys and 30 girls); all were native speakers of Arabic (Palestinian dialect) attending a school in which Arabic is the official language. High school pupils were chosen because many undergraduate students in Israeli universities read Hebrew and English more often than they read Arabic. All participants were volunteers.

### Stimuli and Materials

All stimuli were handwritten by a skilled native speaker of Arabic and were scanned for presentation by a Macintosh SE computer.<sup>4</sup> All stimuli were strings of three to six characters and included the diacritical marks that were part of the consonants as well as some of the vowels. The included vowels were attached to the initial letters to unequivocally specify a meaningful reading (see the Appendixes). However, not all of the vowels were included. There were four stimulus categories: (a) words used in both literary and spoken Arabic, (b) words that exist only in literary Arabic, (c) phonetic transliterations of words that exist only in spoken Arabic, and (d) pseudowords, that is, letter strings that were constructed by replacing one or two letters in

literary words. Hence, the pseudowords were phonologically and orthographically legal in both forms of Arabic but had no meaning in either of them. About one third of the phonetic transliterations included structures that were phonologically illegal in literary Arabic (words beginning with two consonants or with a consonant and a schwa).<sup>5</sup>

The three word categories were further categorized as high or low frequency. In the absence of a computerized word-frequency count in Arabic, frequency was determined empirically by asking 50 high school students (who did not participate in the experiments) to rate the frequency of 480 letter strings. A scale of 1 (*very infrequent*) to 7 (*very frequent*) was used. The stimuli were presented for frequency rating in two lists. One included words that exist either in only literary Arabic or in both literary and spoken Arabic. The other list included words that exist only in the spoken dialect and that thus had no written form. Before rating the spoken-only words, the participants were instructed to use grapheme-to-phoneme translation and to imagine the spoken word that was represented by the print. On the basis of this rating, the high-frequency words selected for the three categories in this study had mean ratings of 6.37, 4.85, and 4.88 for the literary and spoken, literary-only, and spoken-only categories, respectively, whereas the low-frequency words for the three categories had mean ratings of 2.95, 2.04, and 2.04, respectively. The mean length of the stimuli on the screen was 4 cm (ranging from 1.5 cm to 6 cm) seen from a distance of about 70 cm.

### Procedure

Performance in both lexical decision and naming was examined in the first two experiments, whereas only lexical decision was examined in the third experiment. In the lexical-decision task, participants pressed one key with their right-hand index finger for positive answers and pressed another key with their left-hand index finger for negative answers. Naming onset was measured from stimulus onset by a voice

<sup>3</sup> Most of these theories assume the existence of a separate orthographic lexicon from which a phonological (output) lexicon may be addressed. For coherence reasons, while citing these theories, we chose to use our conceptualization of the unified lexicon in which each word entry contains both phonologic and orthographic information. For the present exposition, we do not see radical differences between these two definitions of the lexicon.

<sup>4</sup> In Arabic, there is no difference between print and handwriting. We decided to use calligraphic-written stimuli rather than computer fonts because of the poor quality of the latter.

<sup>5</sup> The illegal nature of these letter strings stems from the phonological differences between spoken and literary Arabic and from the fact that spoken Arabic is usually not written. Hence, two consonants would never occur at the beginning of the word in writing (as the trigram *zbl* does not exist in English written words).

key. The reaction times (RTs) were measured to the nearest millisecond by the computer. Only the RTs for correct responses were included in the analyses.

The experiments were conducted at the school in a relatively quiet classroom. After the instructions were given, 10 practice trials and a *ready* signal preceded each test list. Once the ready signal was on the screen, participants could initiate the test list by pressing a key. The stimuli remained on the screen until a response had been given or for 2.5 s. The interstimulus interval was 2.5 s. Errors were recorded by the computer in the lexical-decision task and by the experimenter in the naming task. Because the same stimuli were used for both naming and lexical decision, different participants were tested for each task. The same participants were examined in Experiments 1 and 2. Each participant was randomly assigned either to lexical decision or to naming tasks. Half of the participants began the session with Experiment 1, and the other half began with Experiment 2.

### Experiment 1

The words used in Experiment 1 were selected from the subset of words that are shared by spoken and literary Arabic. Thus, the participants' performance in this experiment could be compared with performance in most other languages in which lexical decision and naming have been investigated. On the basis of previous studies of lexical decision and naming performance with pointed and unpointed Hebrew words (Bentin & Frost, 1987; Frost, 1994), we predicted that both naming and lexical decision would be faster for high-frequency than for low-frequency words and would be slowest for pseudowords.

### Method

**Participants.** The participants were 40 high school seniors (20 boys and 20 girls). Half of them were instructed to make lexical decisions for the stimuli, and the other half were instructed to name the same stimuli.

**Stimuli.** Ninety-six different stimuli were used: 48 words and 48 pseudowords. The words were from among the subset used in both spoken and literary Arabic. Among them, 24 were high frequency, and 24 were low frequency. One high-frequency word, 4 low-frequency words, and 3 pseudowords had a vowel at onset. The initial consonants in the high-frequency group were 10 stops, 12 fricatives, and one semivowel, and in the low-frequency group, the initial consonants were 14 stops, 4 fricatives, and two semivowels. The mean number of characters per word was not significantly different among stimulus groups (3.8, 4.0, and 3.7 for high-frequency words, low-frequency words, and pseudowords, respectively). The orthographic redundancy (i.e., the number of "neighbors," defined as the value  $N$  representing the number of different words that can be formed by changing only one letter in each stimulus; Coltheart et al., 1977; see also McClelland & Rumelhart, 1981) was similar across groups (1.45, 1.37, and 1.62 for high-frequency words, low-frequency words, and pseudowords, respectively). The Arabic stimuli, their pronunciation, and their English translations are presented in Appendix A.

### Results

Mean RTs for correct responses and percentage of errors were calculated separately for each participant for high- and low-frequency words and for pseudowords.<sup>6</sup> RTs that were above or below two standard deviations from the participants' mean in each condition were excluded, and the mean was

recalculated. About 2% of the trials were excluded by this procedure. These data are presented in Table 2.

Because the method for collecting RT data was different for naming and for lexical decision, these data were analyzed separately for each task. For each task, we have analyzed the stimulus-type effect within subjects ( $F_1$ ) and between stimulus types ( $F_2$ ). Although the difference between the average number of letters per stimulus was similar across stimulus types because low-frequency words had slightly more letters per word than high-frequency words and pseudowords did, the stimulus analysis included the number of letters per stimulus as a covariate.

In the lexical-decision task, the stimulus-type effect was significant,  $F_1(2, 38) = 26.8$ ,  $MSE = 67,029$ ,  $p < .001$ ;  $F_2(2, 92) = 76.3$ ,  $MSE = 30,210$ ,  $p < .001$ . The influence of the stimulus-length covariate on the main effect was not significant,  $F_2(1, 92) = 2.0$ ,  $MSE = 57,425$ ,  $p > .15$ . Post hoc (Tukey  $\alpha$ ) comparisons revealed that although the decisions were significantly faster for high-frequency words than for the other two stimulus types, low-frequency words were not significantly faster than pseudowords were.

A similar pattern of effects was found for naming. The stimulus-type effect was highly significant,  $F_2(2, 38) = 51.3$ ,  $MSE = 5,467$ ,  $p < .001$ ;  $F_2(2, 92) = 31.0$ ,  $MSE = 12,760$ ,  $p < .001$ . The stimulus-length covariate had no influence of the main effect,  $F_2(1, 92) < 1.00$ . Post hoc (Tukey  $\alpha$ ) comparisons revealed that naming of high-frequency words was faster than naming of both low-frequency words and pseudowords. The difference in the speed of naming low-frequency words and pseudowords was significant in the subject analysis ( $p < .05$ ) but not in the stimulus analysis.

The percentages of errors in naming and lexical decision and in each stimulus category were compared with a two-way analysis of variance (ANOVA). This analysis showed that more errors were made in the naming (6.4%) than in the lexical-decision task (4.7%),  $F_1(1, 38) = 4.16$ ,  $MSE = 1.5$ ,  $p < .05$ , but a significant interaction between the task and the stimulus-type effects,  $F_1(2, 76) = 27.13$ ,  $MSE = 1.3$ ,  $p < .0001$ , and post hoc comparisons revealed that for high-frequency words there were more errors in the lexical-decision than in the naming task, whereas for low-frequency words there were more errors in naming than in the lexical-decision task. Finally, for pseudowords the percentage of errors in the two tasks was similar.

### Discussion

The general trend of the results of this experiment resembled that found in similar studies conducted in other languages, but several interesting specificities were found. The most interesting aspect of these data was the unusually large word-frequency effect found in both tasks (464 ms for lexical decision and 181 ms for naming). This large frequency effect

<sup>6</sup> There were no significant hesitations or coughs in the naming task; therefore, all the correct responses were included in the analysis.

Table 2  
*Mean Reaction Times (RTs) in Milliseconds and Percentage of Errors for Words That Exist in Both Literary Arabic and the Palestinian Spoken Dialect and for Pseudowords in the Lexical-Decision and Naming Tasks*

| Word type      | Lexical-decision task |                 |        |                 | Naming task |                 |        |                 |
|----------------|-----------------------|-----------------|--------|-----------------|-------------|-----------------|--------|-----------------|
|                | RT                    | SE <sub>M</sub> | %Error | SE <sub>M</sub> | RT          | SE <sub>M</sub> | %Error | SE <sub>M</sub> |
| High frequency | 614                   | 12              | 5.2    | 0.5             | 634         | 15              | 0.0    | 0.0             |
| Low frequency  | 1,078                 | 44              | 4.8    | 0.5             | 815         | 27              | 15.0   | 1.7             |
| Pseudoword     | 1,133                 | 27              | 4.2    | 0.5             | 856         | 17              | 4.2    | 0.7             |

Note. SE<sub>M</sub> = standard error of the mean.

was not expected, and therefore any explanation must necessarily be post hoc. A possible interpretation is suggested by the fact that, overall, the RTs in both tasks were relatively longer than those reported in similar studies conducted in many other languages (particularly for the low-frequency words), and frequency effects might have been a proportion of the overall RT. In addition, it is possible that the relative slowness of the native speakers of Arabic in these visual word-processing tests reflected a situation in which the participants read a language that they do not usually use and had not mastered well. The previous frequency ratings obtained from other pupils from the same population and the relatively normal percentage of errors in lexical decision suggested that the participants did recognize most of the words. It is possible, however, that the experience that they had with reading the infrequent words was minimal, by far smaller than that typical in other studies. The statistical similarity between the performance with low-frequency words and with pseudowords supports the latter interpretation.

The very large frequency effect in naming, albeit considerably smaller than in lexical decision, was also unprecedented. Such a large effect was particularly unexpected because, although not all the diacritics symbolizing vowels were attached to the consonants, the script included sufficient information to enable reading in an unequivocal manner.<sup>7</sup> Therefore, this pattern contradicts previous reports in which, if the orthography was sufficiently shallow (i.e., the print provided sufficient information to enable prelexical assembling of the phonological structure), frequency effects in naming were small or nonexistent (e.g., Frost, 1994; Frost et al., 1987; Katz & Feldman, 1983). In a nutshell, this sizeable word-frequency effect suggests that lexical phonological information was used to facilitate naming in literary Arabic. We elaborate and discuss the implications of this suggestion in the *Discussion* section of Experiment 2 and in the General Discussion.

## Experiment 2

The stimuli in this experiment were (a) orthographic patterns that represent words in literary Arabic but do not exist in the spoken dialect, (b) transliterations of words in spoken Arabic that do not exist in literary Arabic, and (c) pseudowords, that is, orthographic patterns that were phonologically and orthographically legal in literary Arabic but had no meaning in either of the two forms of the language. The same stimuli were used in both the lexical-decision and the naming tasks, with different participants assigned to each task.

In the lexical-decision task, the participants were instructed to accept only words in literary Arabic and to reject all other stimuli. Because spoken Arabic is never written in Israel,<sup>8</sup> the transliteration of the spoken Arabic words formed orthographic patterns that were very unfamiliar. Moreover, about one third of these patterns contained phonological combinations that are illegal in literary Arabic (see above). Hence, these stimuli may be considered analogous to phonologically illegal nonwords in English. Consequently, if the categorical decision between words and nonwords is based purely on the familiarity of the orthographic patterns, transliterations of spoken words should be rejected easily and at least as fast as pseudowords are. On the other hand, if lexical decision in Arabic involves some phonological computation, transliterations of spoken words might access the phonological lexicon, thus inhibiting their rejection. Such an effect might, in fact, be expected given the similarity of this condition to pseudohomophones in visual lexical decision. As mentioned above, previous studies have shown that nonwords that sound like words (e.g., *brane*) take more time to reject in lexical decision than do orthographically similar nonwords that do not sound like words (e.g., *brate*; Rubenstein et al., 1971). On the other hand, unlike the presently used transliterations, the pseudohomophones used in previous studies sounded like words in the same language in which the real words were presented. Therefore, a pseudohomophone effect could not be a priori predicted for these stimuli without some caution.

Naming performance for literary words and for pseudowords was expected to be similar to that observed in Experiment 1: High-frequency words should be named faster than low-frequency words were, and both should be named faster than pseudowords were. In addition, because the orthographic pattern of the transliterations was totally unfamiliar, literary words should be named faster than spoken words were. According to the accumulating evidence supporting lexical involvement in prelexical assembling of phonological codes (Besner & Smith, 1992; McCann & Besner, 1987), transliterations should be named faster than pseudowords were. On the

<sup>7</sup> Note, however, that not all the diacritics were included. In principle, the participants could have read the words as nonwords, assigning a meaningless pronunciation.

<sup>8</sup> In some Arab countries, there is a tendency to introduce spoken words in newspapers and other popular reading material. Our high-school students, however, do not usually read this literature.

other hand, because the transliterations represented words in a language that was different from the one in which the "real" words were presented, and because the printed form of the transliterations was not only unfamiliar but also strange looking (including orthographic sequences that are totally nonexistent in literary Arabic), it was possible that the transliterations of spoken words would be named as slowly as pseudowords were, and the frequency of the spoken words should not affect naming performance.

## Method

**Participants.** The participants were the same 40 pupils who were tested in Experiment 1. Participants took part in either the lexical-decision or the naming task in both experiments.

**Stimuli.** The stimuli were 24 high-frequency and 24 low-frequency literary words, 24 transliterations of spoken words (12 high-frequency and 12 low-frequency words),<sup>9</sup> and 24 pseudowords. From the participants' point of view, however, there were only two equally represented stimulus categories: legally written literary words and nonwords (including the spoken words).

Among the words in literary Arabic, two high-frequency and seven low-frequency words began with a vowel. The initial consonants in the other high-frequency literary words were 14 stops, four fricatives, and four semivowels. Among the low-frequency literary words that did not begin with a vowel, 12 began with a stop consonant and five began with a fricative. Among the high-frequency transliterations, 1 began with a vowel, 1 began with a semivowel, and 10 began with stop consonants. Among the low-frequency transliterations, one began with a vowel, seven began with stop consonants, and four began with fricatives. Out of the 24 transliterations, three high-frequency and four low-frequency words began with letter combinations that in literary Arabic are not existent (i.e., that were phonologically illegal). The mean word length was similar across groups: 4.5, 4.4, 4.0, 4.2, and 3.8 letters for high-frequency literary words, low-frequency literary words, high-frequency transliterations, low-frequency transliterations, and pseudowords, respectively. There was no significant difference between orthographic redundancy across groups. (The mean *N* values were 0.96 and 1.04 for high- and low-frequency literary words, 0.92 and 0.88 for high- and low-frequency transliterations, and 1.08 for pseudowords). These stimuli are presented in Appendix B.

**Procedure.** The procedure was the same as in Experiment 1. In the lexical-decision task, the instructions indicated the possibility that some of the nonwords might have meaning in spoken Arabic but that these odd stimuli should be rejected. In the naming task, the nature of the stimuli was also explained, but the participant was instructed to simply read the pattern presented on the screen as fast as he or she could. Each task began with 10 practice trials that included all of the kinds of stimuli.

## Results

The RTs were averaged for each stimulus across subjects and for each participant according to five stimulus categories: high-frequency literary words, low-frequency literary words, high-frequency transliterations, low-frequency transliterations, and pseudowords. RTs that were above or below two standard deviations from the subject or the stimulus mean in each category were excluded, and the mean was recalculated.

Less than 3% of the stimuli were outliers equally distributed among stimulus categories.

For both tasks, the RTs for transliterations of spoken words were slower than those for pseudowords, whereas the RTs to literary words were the fastest. High-frequency words were processed faster than low-frequency words were (Table 3). The stimulus-type effect was analyzed separately for each task by one-way ANOVA within subject ( $F_1$ ) and by one-way analysis of covariance (ANCOVA) between stimulus types ( $F_2$ ). The number of letters per stimulus was the covariate variable in the stimulus analysis. The stimulus-type effect was significant for both lexical decision and naming. For the lexical-decision task, ANOVA yielded  $F_1(4, 76) = 21.44$ ,  $MSE = 59,732$ ,  $p < .001$ ;  $F_2(4, 90) = 28.0$ ,  $MSE = 41,044$ ,  $p < .001$ . For the naming task, the statistics were  $F_1(4, 76) = 22.0$ ,  $MSE = 8,423$ ,  $p < .001$ ;  $F_2(4, 90) = 5.76$ ,  $MSE = 32,858$ ,  $p < .001$ . The influence of the number of letters per stimulus on the stimulus-type effect was marginal and was not statistically significant either for lexical decision ( $p > .06$ ) or for naming ( $p > .07$ ). Tukey *a* post hoc comparisons revealed the following pattern: In the lexical-decision task, the rejection of both high- and low-frequency transliterations of spoken words was slower than the rejection of pseudowords was. The frequency effect was significant for the acceptance of literary words but not for the rejection of the transliterations. In the naming task, low- but not high-frequency transliterations were slower than pseudowords were, whereas high- but not low-frequency literary words were named faster than pseudowords were. Within each frequency group, transliterations of spoken words were named more slowly than literary words were. Because of the excessive number of errors in naming low-frequency transliterations (Table 3), we analyzed the naming data with only 12 participants who made less than 50% errors in that condition. The RTs and the results of that analysis were similar to the above.

The effect of language on naming was also examined by a two-variable ANOVA with repeated measures. The variables were language (literary and spoken) and frequency (high and low). Literary words were named faster than spoken words were,  $F_1(1, 19) = 25.9$ ,  $MSE = 17,810$ ,  $p < .001$ ;  $F_2(1, 68) = 13.8$ ,  $MSE = 32,788$ ,  $p < .001$ , and high-frequency words were named faster than low-frequency words were,  $F_1(1, 19) = 36.1$ ,  $MSE = 5,992$ ,  $p < .001$ ;  $F_2(1, 68) = 6.3$ ,  $MSE = 32,788$ ,  $p < .02$ . The interaction between the language and the frequency effects was significant in the subject analysis,  $F_1(1, 19) = 18.0$ ,  $MSE = 3,526$ ,  $p < .001$ , but not in the stimulus analysis,  $F_2(1, 68) < 1.0$ .

More errors were made in the naming task (16%) than in the lexical-decision task (5%),  $F_1(1, 38) = 52.76$ ,  $MSE = 2.5$ ,  $p < .0001$ ;  $F_2(1, 38) = 34.02$ ,  $MSE = 1.8$ ,  $p < .001$ . The stimulus-type effect was significant across tasks,  $F_1(4, 152) = 28.1$ ,  $MSE = 1.1$ ,  $p < .0001$ ;  $F_2(4, 180) = 31.45$ ,  $MSE = 0.9$ ,  $p < .0001$ , as was the interaction between the two variables,  $F_1$

<sup>9</sup> Because the most interesting comparison in this experiment was between transliterations of spoken words and legal nonwords and to maintain a 1:1 ratio between *yes* and *no* responses, the number of spoken words presented was equated to the number of nonwords rather than to the number of literary words.

**Table 3**  
*Reaction Times (RTs) in Milliseconds and Percentage of Errors in the Lexical-Decision Task and in Naming for Words That Exist Only in Literary Arabic or Only in the Spoken Dialect and for Pseudowords*

| Word type       | Lexical-decision task |                 |        |                 | Naming task |                 |        |                 |
|-----------------|-----------------------|-----------------|--------|-----------------|-------------|-----------------|--------|-----------------|
|                 | RT                    | SE <sub>M</sub> | %Error | SE <sub>M</sub> | RT          | SE <sub>M</sub> | %Error | SE <sub>M</sub> |
| Yes response    |                       |                 |        |                 |             |                 |        |                 |
| Literary Arabic |                       |                 |        |                 |             |                 |        |                 |
| High frequency  | 887                   | 43              | 5.4    | 0.6             | 721         | 28              | 2.1    | 0.7             |
| Low frequency   | 1,411                 | 92              | 4.8    | 0.5             | 881         | 44              | 16.2   | 1.8             |
| No response     |                       |                 |        |                 |             |                 |        |                 |
| Spoken dialect  |                       |                 |        |                 |             |                 |        |                 |
| High frequency  | 1,377                 | 99              | 3.3    | 0.9             | 929         | 49              | 13.7   | 1.9             |
| Low frequency   | 1,517                 | 113             | 5.4    | 0.9             | 977         | 56              | 41.7   | 3.8             |
| Pseudoword      | 1,140                 | 111             | 5.8    | 0.7             | 877         | 49              | 7.9    | 1.3             |

Note. SE<sub>M</sub> = standard error of the mean.

(4, 152) = 37.32, MSE = 1.1, *p* < .0001; *F*<sub>2</sub> (4, 180) = 34.87, MSE = 0.9, *p* < .0001. The interaction was examined by a separate one-way ANOVA for each task. These analyses showed that errors in lexical decision were evenly distributed among the stimulus categories, *F*<sub>1</sub>(4, 76) = 1.66, MSE = 0.011, *p* > .18; *F*<sub>2</sub> < 1.00. In naming, on the other hand, the percentage of errors was different for the different types of stimuli, *F*<sub>1</sub>(4, 76) = 64.41, MSE = 0.7, *p* < .0001; *F*<sub>2</sub>(4, 90) = 48.35, MSE = 0.9, *p* < .0001. Post hoc comparisons showed that for both literary and spoken words more errors were made with low- than with high-frequency words and that pseudowords produced fewer errors than low-frequency words did.

### Experiment 2A

Because spoken and literary Arabic differ in several important phonological aspects, it is possible that the frequency and the language effects on naming reflected difficulties at the production stage. To control for this possibility, a delayed naming task was also investigated (e.g., Besner & Hildebrandt, 1987).

### Method

Sixteen new participants from the same population were asked to read aloud all the stimuli used in Experiment 2. They were instructed,

however, to delay reading onset until a signal was given. The signal was an asterisk that was presented 2.5 s after the onset of the stimulus. The exposure time of each word was 2 s.

### Results

The delayed naming times and the percentage of naming errors are presented in Table 4. A within-subject ANOVA showed that delayed naming time was equal across stimulus types, *F*<sub>1</sub>(4, 60) = 1.19, MSE = 8,455, *p* > .30; *F*<sub>2</sub>(4, 91) = 1.77, MSE = 7,894, *p* > .15. Hence, under these circumstances, naming was equally fast for words in literary Arabic (363 ms) and in spoken Arabic (379 ms) and for pseudowords (360 ms). Furthermore, although there was a tendency to name high-frequency words faster than low-frequency words (355 ms vs. 387 ms, respectively), a Frequency × Language ANOVA showed that this difference was insignificant, *F*<sub>1</sub>(1, 15) = 2.43, MSE = 7,748, *p* > .14; *F*<sub>2</sub>(1, 68) = 1.82, MSE = 9,096, *p* < .18, and that the two effects did not interact, *F*<sub>1</sub>(1, 15) = 1.64, MSE = 9,276, *p* > .22; *F*<sub>2</sub>(1, 68) = 1.72, MSE = 9,096, *p* < .19. The errors analysis, on the other hand, showed that even when naming was delayed, the distribution of errors was not even across the stimulus types, *F*<sub>1</sub>(4, 60) = 18.7, MSE = 41.9, *p* < .001; *F*<sub>2</sub>(4, 91) = 13.5, MSE = 51.1, *p* < .001. Post hoc comparisons revealed that more errors were made in naming transliterations of low-frequency words than in naming any

**Table 4**  
*Reaction Times (RTs) in Milliseconds and Percentage of Errors in the Delayed Naming Task for Words That Exist Only in Arabic or Only in the Spoken Dialect and for Pseudowords*

| Word type       | Delayed naming task |                 |        |                 | Immediate minus delayed |        |
|-----------------|---------------------|-----------------|--------|-----------------|-------------------------|--------|
|                 | RT                  | SE <sub>M</sub> | %Error | SE <sub>M</sub> | RT                      | %Error |
| Literary Arabic |                     |                 |        |                 |                         |        |
| High frequency  | 331                 | 12              | 2.1    | 0.61            | 390                     | 0.1    |
| Low frequency   | 395                 | 20              | 5.5    | 1.08            | 486                     | 10.8   |
| Spoken dialect  |                     |                 |        |                 |                         |        |
| High frequency  | 379                 | 40              | 10.4   | 3.10            | 550                     | 4.4    |
| Low frequency   | 380                 | 27              | 19.7   | 3.80            | 597                     | 22.0   |
| Pseudoword      | 359                 | 13              | 6.0    | 1.09            | 518                     | 2.1    |

Note. SE<sub>M</sub> = standard error of the mean.

other type of stimulus, and fewer errors were made in naming high-frequency literary words than in naming high-frequency transliterations. Naming of pseudowords was as accurate as naming of all other stimulus types except for low-frequency transliterations.

### Discussion

One of the most interesting results of Experiment 2 was that transliterations of spoken words were processed more slowly than pseudowords were. Similar to the pseudohomophone effect in English or Hebrew, the rejection of transliterations of both high- and low-frequency words in the spoken dialect was delayed in lexical decision relative to the rejection of pseudowords derived from literary Arabic. Similarly, the naming of both high- and low-frequency transliterations was also delayed relative to pseudowords, although this difference was statistically significant only for the low-frequency stimuli. The word-frequency effect was significant for literary words in both lexical decision and in naming. On the other hand, the numerically faster RTs for high-frequency than for low-frequency transliterations were insignificant in lexical decision (where these transliterations had to be rejected), whereas in naming they were significant only for the subject analysis. The direction of the differences in the error data was similar to that found for RTs, suggesting that the stimulus-type effects on RTs were not caused by a speed-accuracy trade-off. When naming was delayed by 2.5 s, RTs were similar across conditions, but naming of the low-frequency spoken words was still highly inaccurate (20% errors) and was significantly less accurate than naming of any other stimulus type.

The general similarity of the pattern of results in naming and lexical decision suggests that postlexical, decision-related factors cannot totally account for the stimulus-type effects found in this experiment. Furthermore, the fact that the RTs in the delayed naming experiment were similar across stimulus type indicates that an important part of this effect, at least in naming, was related to stimulus encoding rather than to production factors. However, the unusually large percentage of errors in naming low-frequency transliterations, which persisted even when naming was delayed, suggests that these stimuli presented a particular problem to the participants.

Unlike pseudohomophones, the transliterations of spoken words were not constructed by substituting allophones for one or two letters in real literary words. Therefore, orthographic similarity to items in the word category could not account for the delayed rejection of these stimuli relative to pseudowords (cf. Taft, 1982). In fact, the participants in the present experiment had no previous experience with the transliterations of spoken words. Informal comments made by most participants while performing the tasks expressed their surprise that spoken words could also be written. Therefore, if the familiarity of the orthographic patterns had been a major factor in determining the speed of the lexical decision, the transliterations should have been rejected as fast as pseudowords were or even faster, because some of these strings included combinations of letters that are illegal in written Arabic (cf. Balota & Chumbley, 1984). Consequently, the fact that these stimuli took longer to reject than pseudowords did

can be more easily explained by assuming that during the process of lexical decision, the phonological representations of the transliterations (i.e., the phonological units representing words in spoken Arabic) had been activated.

Why should the lexical activation of words in spoken Arabic delay their rejection in a task in which only words in literary Arabic should be classified in the *positive* category? A possible explanation is that, once the lexicon was accessed and particularly because literary and spoken Arabic share a subset of words, lexical decisions required an additional classification—one between literary and spoken words. This additional classification was not necessary for pseudowords, because pseudowords do not fully activate lexical units. Note that this mechanism should have delayed lexical decisions for both literary and spoken words. Indeed, a comparison between lexical-decision RTs in Experiment 1 and in Experiment 2 revealed that, whereas for pseudowords the mean RT was almost identical in both experiments, the RTs for literary words were significantly longer in Experiment 2 than in Experiment 1. This difference was particularly conspicuous for low-frequency words. In fact, in Experiment 2, the time required to accept low-frequency literary words was longer than the time required to reject pseudowords.

Although the above interpretation suggests that the delay in lexical decision for both literary words and transliterations could partly be explained by decision-related processes, it is based on the assumption that the phonological representations in the lexicon are activated *before* the lexical decision is made. Furthermore, because the orthographic pattern of the transliterations could not have been used to address whole-word phonologic representations, the activation of these lexical units necessarily required some prelexical phonological computation. The stimulus-type effect on naming performance (which does not involve decision processes) supported this argument and helped elaborate the nature of the lexical involvement in the phonological processing of written Arabic words.

Naming of transliterations of spoken words was slower and less accurate than naming of literary words was. These results are congruent with the relationship between naming orthographically familiar and unfamiliar words in Katakana (Besner & Hildebrandt, 1987) as well as with the relationship between naming pseudohomophones and nonwords in English (McCann & Besner, 1987; Taft & Russell, 1992). The frequency effects found in naming performance for both literary and spoken words suggest that lexical phonology assists phonological encoding not only when whole-word phonological units are addressed in the lexicon but also when phonology is prelexically assembled.

A caveat to this interpretation was introduced by the unpredicted result that naming of transliterations was also slower (at least for the low-frequency spoken words) than naming of pseudowords was. This relationship is in sharp contrast with the results reported by Besner and Hildebrandt (1987) who used a fairly similar manipulation. In that study, native speakers of Japanese were asked to read aloud words printed in Katakana (one of the two Japanese syllabic scripts). Some of these stimuli were words that are usually written in Kanji (a logographic script); hence, they were orthographically unfamiliar to the participants. Although these orthographi-



cally unfamiliar words were read more slowly than orthographically familiar words were, in contrast to the present results, they were faster than were orthographically matched non-words.<sup>10</sup> A possible (post hoc) explanation of the unexpected difference in the naming of transliterations and pseudowords as well as an account of the other results of this experiment is provided by a model recently proposed to account for naming in Hebrew (Frost, 1995).

According to Frost's (1995) model, generating phonology from print consists first of a computational stage during which a tentative phonological representation is formed, thereby converting letters and letter clusters into phonemes and phonemic clusters. According to our interpretation of Frost's model, the size of the orthographic unit used in that computation may vary from single letters (when the letter string does not contain familiar orthographic structures) to whole words (when the letter string is very familiar). We assume that most of the time this computation is based on a combination of letters and subword orthographic structures. Partial results of this computational analysis are sufficient to feed forward and to activate a set of whole-word lexical units (at which stage frequency effects may occur). The lexical units feed back and help shape the computational process, allowing a correct pronunciation. The process thereby combines a cascade-type process (e.g., McClelland, 1979) with an interactive process (Seidenberg & McClelland, 1989) during which different lexical units are activated to different extents (depending on their respective compatibility with the partial ad hoc phonological output of the computational process). The feedback from the lexicon to the prelexical computational system might, in turn, determine the relative level of activation of these units.

According to this model, the naming of the transliterations was slowed down during the initial computational stage. This could have happened for several reasons. First, the stimuli looked sufficiently unfamiliar to prevent any attempt to address whole-word units in the lexicon. Second, because the spoken Arabic dialect is never written and because words from the spoken dialect were randomly interspersed among twice as many normal (literary) words, the partial products of the computational phonological process might have been addressed to the literary lexicon. Consequently, the information available in the spoken-words lexicon might have been late to intervene and might not have facilitated naming. Third, as described above, some of the transliterations contained letter sequences that were either completely illegal in normal print or had a different pronunciation that did not fit the spoken lexicon. Pseudowords, on the other hand, were not inhibited by either the lexical process or orthographical irregularity. Therefore, reading the transliterations was more difficult than reading the pseudowords was. Note that this situation is considerably different from the orthographically unfamiliar words in Katakana that addressed the same lexicon as the familiar words did. Support for these assumptions and particularly for the difficulty in naming the illegal clusters was provided by the analysis of errors.

More errors were made in naming transliterations than in naming literary words. The most striking aspect of the distribution of errors was the excessively high percentage of errors in naming low-frequency transliterations. Half of these errors

(21%), however, were made with the four transliterations that had a phonologically illegal onset. Similarly, among the errors made in naming the high-frequency transliterations, 10% were made with the three phonologically illegal clusters in this group. If we consider only the errors made in naming phonologically legal words, we are left with an expected error rate for high-frequency words but an unusually high error rate for low-frequency words. Moreover, some of these errors persisted even when naming was delayed. These errors consisted mostly of using the literary pronunciation of the letter clusters while reading the transliterations.

Our account of the lexical-decision results in this experiment suggested a second stage of processing during which spoken words had to be distinguished from literary words. This second stage was necessary because literary and spoken words had to be classified in different response categories. To control for this problem and to get a "cleaner" measure of the difficulty in processing the transliterations, we ran an additional experiment in which participants were asked to make a phonological lexical decision (i.e., to accept any legal Arabic word and to reject only the pseudowords).

### Experiment 3

In this experiment, participants were instructed to silently read the visually presented stimuli and to make a phonologically based lexical decision (e.g., Taft, 1982). They were told to accept as words any letter string that sounded like a word in Arabic, regardless of whether the phonological product was a word in literary Arabic or in the spoken dialect.

If lexical decisions in the previous experiment were delayed (particularly for transliterations) mainly because a secondary classification between literary and spoken words was imposed by the task, then the difference between literary and spoken words in this experiment should be minimal. On the other hand, if our model of word recognition is correct, the phonological computation should be more difficult for the transliterations than for the literary words, regardless of the response category to which these stimuli must be assigned. Consequently, we predicted that phonological decisions would take longer for the transliterations of spoken words than for the literary words.

### Method

*Participants.* The participants were 20 high school pupils (10 boys and 10 girls). They were naive about the purpose of the study and had not participated in any of the previous experiments.

*Stimuli.* The stimuli were 96 words and 96 nonwords. Among the words, 48 were the literary Arabic stimuli used in Experiment 2, and 48 were transliterations of spoken Arabic words; the transliterations were the 24 used in Experiment 2 and 24 new words: 12 high- and 12 low-frequency words (see Appendix C). The pseudowords were the 48 used in Experiment 2 and 48 additional stimuli constructed by

<sup>10</sup> Note, however, that the difference between orthographically unfamiliar words and nonwords also persisted when naming was delayed. Although the authors suggested that this persistence was caused by an insufficient delay of naming (1 s), these results cannot be considered conclusive.

replacing one letter in literary Arabic words. All pseudowords were meaningless but phonologically legal.

**Design.** The RTs were grouped with a univariate five-level design within subjects and between stimuli. The levels were high-frequency literary, low-frequency literary, high-frequency spoken, low-frequency spoken, and pseudowords. As in the previous experiments, the stimulus analysis was based on an ANCOVA controlling for the number of letters per stimulus (which was used as the covariate). In addition, the responses to literary and spoken words were compared with a Frequency  $\times$  Language within-subject and between-stimulus design.

**Procedure.** The procedure was similar to that used in Experiment 2 except that the participants were told that some of the letter strings would be transliterations of spoken words, and they were instructed to distinguish between all words (whether spoken or literary) and pseudowords.

## Results

RTs and errors were averaged for each stimulus condition across subjects and stimuli. RTs above or below two standard deviations from the subject or the stimulus mean in each condition were excluded. About 2% of the responses were outliers, which were equally distributed across conditions. RTs for spoken words were slower than for both literary words and pseudowords (Table 5).

The statistical analysis showed that the stimulus-type effect was significant,  $F_1(4, 76) = 29.04$ ,  $MSE = 37,754$ ,  $p < .001$ ;  $F_2(4, 186) = 44.5$ ,  $MSE = 28,859$ ,  $p < .001$ . The stimulus length did not influence this main effect,  $F_2(1, 186) = 1.29$ ,  $MSE = 56,425$ ,  $p > .25$ . Post hoc comparisons showed that all the differences between any two single categories were significant, except for the difference between low-frequency literary words and pseudowords. The Frequency  $\times$  Language ANOVA showed that responses to spoken words were slower than responses to literary words were,  $F_1(1, 19) = 223.0$ ,  $MSE = 972$ ,  $p < .001$ ;  $F_2(1, 91) = 66.8$ ,  $MSE = 37,862$ ,  $p < .001$ . High-frequency words were faster than low-frequency words were,  $F_1(1, 19) = 55.6$ ,  $MSE = 34,047$ ,  $p < .001$ ;  $F_2(1, 91) = 41.9$ ,  $MSE = 37,862$ ,  $p < .001$ , but a significant interaction between the two variables revealed that the frequency effect was significantly larger for literary words (403 ms) than for

spoken words (212 ms),  $F_1(1, 19) = 14.4$ ,  $MSE = 12,917$ ,  $p < .01$ ;  $F_2(1, 91) = 5.6$ ,  $MSE = 37,862$ ,  $p < .025$ . As in the one-way ANCOVA, the stimulus length did not influence these effects ( $p > .6$ ).

To estimate the contribution of the decision-related variable to lexical-decision performance, in Experiment 2 we compared the RTs for literary words in the two experiments. Note that in both experiments these stimuli were accepted as real words. A mixed-model ANOVA was used in which experiment was a between-subject variable and word frequency was a within-subject variable. This analysis revealed that literary words were accepted faster in Experiment 3 (994 ms) than in Experiment 2 (1,149 ms),  $F(1, 38) = 4.0$ ,  $MSE = 119,538$ ,  $p < .056$ , and that high-frequency words were accepted faster than low-frequency words were in both experiments,  $F(1, 38) = 119.8$ ,  $MSE = 35,870$ ,  $p < .001$ , whereas the interaction between the two variables was not significant,  $F(1, 38) = 2.046$ ,  $MSE = 35,870$ ,  $p > .16$ . In contrast, the rejection of pseudowords was equally fast in both experiments,  $t(38) = 0.774$ ,  $p > .48$ .

An analysis of the errors indicated that the differences between stimulus categories were not significant within subjects,  $F_1(4, 76) = 1.67$ ,  $MSE = 0.06$ ,  $p > .16$ . However, the between stimulus-type analysis followed by Tukey *a* post hoc comparisons showed that more errors were made with low-frequency words (literary and spoken) than with high-frequency words or pseudowords,  $F_2(4, 186) = 32.41$ ,  $MSE = 4.7$ ,  $p < .0001$ .

## Discussion

The results of this experiment demonstrated that the delay in processing transliterations of spoken words resulted from prelexical encoding difficulties as well as from decision-related factors. On the one hand, lexical decisions were slower for transliterations than for literary words, even though the decision was phonologically based (i.e., both literary and spoken words were classified in the same response category). Hence, assuming that our participants were at least as familiar with the phonological representations of spoken words as they were with those of literary words, the delay in the phonological lexical decision for the spoken words relative to the literary words indicates that the process of generating the phonological code from the transliterations was slower (more difficult) than the process for literary words. On the other hand, literary words were accepted faster in this experiment (in which phonological decisions were required) than in Experiment 2 (in which the decisions could, at least according to some theories, be based on the visual familiarity of the orthographic patterns). This outcome supports our assumption that, in Experiment 2 as well as in the present experiment, lexical decisions were based on the phonological structure of the visual stimuli and that, given the nature of the task, a second distinction between spoken and literary words was necessary only there.

Assuming that lexical decision requires the recovery of the phonological structure of printed words, we suggest that this process has similar components in naming and in lexical decision. Thus, generating the phonological structure was faster for literary than for spoken words because (a) the

Table 5  
Reaction Times (RTs) in Milliseconds and Percentage of Errors in the Phonological Lexical-Decision Task for Words That Exist Only in Literary Arabic or Only in the Spoken Dialect and for Pseudowords

| Word type       | Lexical-decision task |        |        |        |
|-----------------|-----------------------|--------|--------|--------|
|                 | RT                    | $SE_M$ | %Error | $SE_M$ |
|                 | Yes response          |        |        |        |
| Literary Arabic |                       |        |        |        |
| High frequency  | 793                   | 33     | 5.4    | 0.53   |
| Low frequency   | 1,196                 | 65     | 3.7    | 0.73   |
| Spoken dialect  |                       |        |        |        |
| High frequency  | 1,210                 | 42     | 5.6    | 0.55   |
| Low frequency   | 1,422                 | 69     | 4.8    | 0.62   |
|                 | No response           |        |        |        |
| Pseudowords     | 1,032                 | 86     | 4.8    | 0.31   |

Note.  $SE_M$  = standard error of mean.

orthographic patterns of literary words were relatively more familiar, and therefore some of these stimuli could directly address whole-word phonological units in the lexicon; (b) spoken words are not usually written, and therefore when transliterations were processed, the partial phonologic output of the prelexical computation might have been addressed (by rule) first to the literary lexicon; and (c) the unusual combination of letters might have inhibited prelexical computation of the transliterations and might have limited the size of the orthographic structure used in the translation process to single phonemes.

### General Discussion

The present study was aimed at examining the role of phonology in lexical decision and naming by assessing the effects of the phonological structure of orthographic patterns representing words in spoken Arabic on lexical decision and naming performance. Because only literary Arabic is written, transliterations of words that are specific to the spoken Palestinian dialect were novel orthographic stimuli for all of our participants. Consequently, unless the phonologic structure of the orthographic pattern was processed by the reader while performing these tasks, transliterations should have been treated as unfamiliar nonwords.

The results of the three experiments can be summarized as follows. Both lexical decision and naming performance were inhibited during the processing of the transliterations in comparison with literary words and pseudowords derived from literary Arabic. Transliterations of spoken words were more difficult to reject than were meaningless pseudowords (Experiment 2), but they were also accepted more slowly than were literary words in a phonologically based lexical-decision task (Experiment 3). Lexical decisions were inhibited for both literary and spoken words when transliterations had to be rejected compared with a condition in which all the words were in literary Arabic (Experiment 1) or to a condition in which the decision was phonologically based. Naming of transliterations took longer and was less accurate than naming of literary words. Unexpectedly, naming of transliterations was also slower and less accurate than naming of pseudowords was, although the latter difference was significant only for low-frequency stimuli. Finally, an unusually large word-frequency effect was found in naming as well as in making positive lexical decisions for both literary and spoken words.

These data are congruent with views suggesting that word recognition is always mediated by phonology. The participants in the present study did not ignore the phonological structure of the transliterations, even though ignoring it would have facilitated the lexical decision. Moreover, the longer RTs for literary Arabic words when transliterations had to be rejected (Experiment 2) than when phonological analysis was imposed by the task (Experiment 3) strongly suggest that even if given the option to use the orthographic pattern for lexical categorization (and, in fact, this strategy would have been the most efficient), participants could not ignore the phonological structure of the *literary* words. Hence, familiar as well as unfamiliar orthographic patterns are analyzed phonologically during the course of lexical decision.

This is not to say, however, that phonology is always prelexically computed (cf. Frost, 1995). In that article, Frost distinguished between a strong and a weak version of the phonological mediation theory. According to the strong version, the initial process of recovering phonologic information from print necessarily involves the translation of graphemes into phonemes and does not make use of the notion of addressed phonology (i.e., accessing whole-word phonologic units by using whole-word orthographic patterns; Carello et al., 1992; Lukatela & Turvey, 1990; Van Orden et al., 1990). In contrast, the weak version of the phonological mediation theory, although still emphasizing that phonological encoding is obligatory and necessarily mediates word recognition, views the generation of phonology from print as a process that involves computations at the level of subword orthographic units in addition to direct connections between whole-word orthographic units and whole-word phonologic units. Obviously, prelexical computation and addressed phonology are not mutually exclusive. In fact, both processes may be attempted in parallel, and to some extent they support each other. What determines the relative contribution of these two processes to the retrieving of the phonological structure of a printed word is the ease with which prelexical phonology can be achieved. Thus, when the orthographic patterns of the words are relatively unfamiliar, for example, infrequent words (Seidenberg, 1985a) or are very unfamiliar as with pseudowords, prelexical computations are dominant. On the other hand, when the orthographic pattern is very familiar, or the subword orthographic units are phonologically ambiguous (e.g., with phonologically irregular words), or both or when the print provides only incomplete phonological information (such as in unpointed Hebrew or Arabic), addressed phonology could have a more important role (Frost et al., 1987). Although the present data do not disprove the strong version of the phonological mediation theory, they are more easily accommodated by its weak version. Note that support for the strong version has been mainly indirect, through demonstrations that all lexical effects on naming can be explained without assuming addressed phonology. Until recently, empirical evidence has been provided for reading only very shallow orthographies, such as Serbo-Croatian (e.g., Lukatela, Turvey, Feldman, Carello, & Katz, 1989). In his recent article, however, Frost (1995) supported the strong version of the orthographic mediation theory by showing that for unpointed Hebrew words of equal length and frequency, naming but not lexical-decision time is positively and monotonically related to the number of missing phonemic units. Moreover, word-frequency effects in naming were found only when phonemic information was missing but not when it was complete.

Contrary to Frost's (1995) results, we found that naming of Arabic words was significantly influenced by word frequency, even though sufficient phonemic information was provided to enable unequivocal pronunciation (although not all the diacritical marks were added). Moreover, the huge word-frequency effect in both naming and lexical decision, which was more than three times as big for literary as for spoken words, suggests a qualitative difference in the processing of high- and low-frequency literary words. It is reasonable to assume that, although a relatively large proportion of high-frequency printed

literary words could rapidly retrieve their phonological structure through associative connections between whole-word orthographic patterns and whole-word phonological units, addressed phonology was not an option for transliterations and for low-frequency literary words. This hypothesis is also supported by comparisons between the word-frequency effects on naming regular words versus naming exception words (Seidenberg et al., 1984; Taraban & McClelland, 1987), by comparisons between word-frequency effects on naming in languages with deep and shallow orthographies (Frost et al., 1987), and by morphological or prosodic manipulations (Monsell, 1991; Monsell, Doyle, & Haggard, 1989; Paap, McDonald, Schvaneveldt, & Noel, 1987).

Other studies, however, have raised doubts about the role of word frequency in lexical access and suggest that word-frequency effects in naming reside in the connection between visually accessed lexical entries and their articulatory output (McCann & Besner, 1987) and that in lexical decision it plays a role only at a postlexical decision stage (Balota & Chumbley, 1984). The present results indicate that phonological encoding factors probably account for most of the word-frequency effects in naming and suggest a prelexical as well as a decision-related influence of word-frequency in lexical decision.

The word-frequency effect on phonological decisions for both literary words and transliterations of spoken words (which contradicts the results reported by McCann, Besner, & Davelaar, 1988) and particularly the large frequency effects in naming transliterations of spoken words (which contradicts the results reported by McCann & Besner, 1987) indicate that word frequency has a role in phonological encoding and lexical access (see also Taft & Russell, 1992). Additional support for this claim was provided by the delayed naming experiment where naming time was not affected by word frequency (see also Monsell et al., 1989). Moreover, as elaborated in the *Discussion* section of Experiment 2, the present data indicate that lexical phonology is directly involved in prelexical phonological computation even when addressed phonology is impossible.

With regard to lexical decision, Balota and Chumbley's (1984, 1985) two-stage model suggests that word frequency determines the value of the stimulus on a familiarity-meaningfulness (FM) dimension. Because the same transliterations were used in Experiment 2 and in Experiment 3, their FM values must have been the same in both experiments. Therefore, if word frequency had affected only decision strategies, it should have had an opposite effect on opposite decisions. Yet, lexical decision for high-frequency words was faster than for low-frequency words both when the participant accepted these stimuli as words and when the stimuli were rejected. Note, however, that the frequency effect was statistically significant only for the phonological lexical decisions.

In conclusion, this study provides additional evidence that phonological information is automatically analyzed during visual-word recognition (cf. Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988) and that the phonological structure of printed words is used by the reader during word recognition. Unlike strong versions of the phonological mediation theory, however, we assume that the orthographic pattern of very

frequent words may be associated with whole-word phonological units in the lexicon and that these associations may be used to retrieve the word's phonological structure by addressing the lexicon directly. These data are not supportive of models suggesting that word recognition in general and lexical decisions in particular can be based solely on visual familiarity and orthographic analysis (e.g., Besner & McCann, 1987). The word-frequency effect on processing literary and spoken words supports Monsell's (1991) suggestion that the effect of frequency reflects lexical transcoding from orthography to phonology and suggests that lexical phonology may contribute to this process by shaping prelexical phonological computation even when addressed phonology is not possible. A model accounting for this pattern may combine a cascade-type feed-forward activation of lexical phonological units by partial output of prelexical phonological computation (e.g., McClelland, 1979) with feedback from the activated units that may shape prelexical computation (e.g., McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982).

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## Appendix A

## Words Used in Experiment 1

| High-frequency word | Approximate pronunciation | Meaning    | Low-frequency word | Approximate pronunciation | Meaning        |
|---------------------|---------------------------|------------|--------------------|---------------------------|----------------|
| قلم                 | kalam                     | pen        | طاريد              | tarida                    | insanity       |
| مدرسه               | madrasah                  | school     | طابق               | tagia                     | gorge          |
| كثير                | kathir                    | much       | واكاه              | waakah                    | pain           |
| سؤال                | sual                      | question   | كارخا              | karixa                    | appetite       |
| نار                 | nar                       | fire       | مناكاسا            | munakasa                  | auction        |
| شمعة                | shamaah                   | candle     | تاازام             | taazam                    | got in trouble |
| دفتر                | daftar                    | copybook   | مخاضان             | muxasan                   | fortified      |
| شجرة                | shajara                   | tree       | مورتازاكا          | murtazaka                 | mercenary      |
| صورة                | surah                     | picture    | خاشيا              | xashia                    | entourage      |
| باب                 | bab                       | door       | واخله              | waxlah                    | sudden         |
| شباك                | shubak                    | window     | ماكتوم             | maktum                    | hidden         |
| أرض                 | ard                       | land       | خانسار             | xansar                    | little finger  |
| بحر                 | baxr                      | sea        | تاكاشوف            | takashuf                  | modesty        |
| صيف                 | sayf                      | summer     | تافان              | tufan                     | deluge         |
| سطح                 | satx                      | roof       | عركاله             | arkalah                   | failure        |
| شهر                 | shahr                     | month      | كاوميا             | kaumiah                   | nationality    |
| شارع                | sharia                    | road       | يبزيم              | ybyzim                    | buckle         |
| فنجان               | funjan                    | cup        | لوزوم              | luzum                     | need           |
| دار                 | dar                       | house      | تالابيا            | talabiah                  | petition       |
| صحن                 | saxyn                     | plate      | ينشاكاه            | ynshaka                   | cracked        |
| شمس                 | shams                     | sun        | تاشات              | tashat                    | spread         |
| مدير                | mudeer                    | director   | تااماد             | taamad                    | premediated    |
| معلم                | muallem                   | teacher    | خاسناه             | xasanah                   | immunity       |
| لوح                 | laux                      | blackboard | فاكفا              | faxfafa                   | wealth         |

Note. All the words are used in both literary and spoken Arabic.

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## Appendix A

## Words Used in Experiment 1

| High-frequency word | Approximate pronunciation | Meaning    | Low-frequency word | Approximate pronunciation | Meaning        |
|---------------------|---------------------------|------------|--------------------|---------------------------|----------------|
| تَم                 | kalam                     | pen        | طَرِيه             | tarida                    | insanity       |
| مَدْرَسَة           | madrrasah                 | school     | طَائِيه            | tagia                     | gorge          |
| كَثِيْر             | kathir                    | much       | وَعَكَة            | waakah                    | pain           |
| سُؤَال              | sual                      | question   | كَرْيَخَة          | karixa                    | appetite       |
| نَار                | nar                       | fire       | مُنَاكَسَا         | munakasa                  | auction        |
| شَمَاعَة            | shamaah                   | candle     | تَاَزَام           | taazam                    | got in trouble |
| دَفْتَر             | daftar                    | copybook   | مُخَسَن            | muxasan                   | fortified      |
| شَجَرَة             | shajara                   | tree       | مُرتَزَاكَا        | murtazaka                 | mercenary      |
| صُورَة              | surah                     | picture    | خَاشِيَا           | xashia                    | entourage      |
| بَاب                | bab                       | door       | وَاخْلَا           | waxlah                    | sudden         |
| سُتَاك              | shubak                    | window     | مَاكْتُم           | maktum                    | hidden         |
| أَرْض               | ard                       | land       | خَاسَر             | xansar                    | little finger  |
| بَحْر               | baxr                      | sea        | تَاكَاشُف          | takashuf                  | modesty        |
| صَيْف               | sayf                      | summer     | تُفَان             | tufan                     | deluge         |
| سَطْح               | satx                      | roof       | أَرْكَالَاه        | arkalah                   | failure        |
| شَهْر               | shahr                     | month      | كَاوْمِيَا         | kaumiah                   | nationality    |
| شَارِع              | sharia                    | road       | يُبْزِيْم          | ybyzm                     | buckle         |
| كُؤَان              | funjan                    | cup        | لُزُوم             | luzum                     | need           |
| دَار                | dar                       | house      | تَالَابِيَا        | talabyah                  | petition       |
| صَاقِيْن            | saxyn                     | plate      | يُنْشَاكَا         | ynshaka                   | cracked        |
| شَمْس               | shams                     | sun        | تَاشَاتَات         | tashatat                  | spread         |
| مُدِير              | mudeer                    | director   | تَاَامَاد          | taamad                    | premediated    |
| مُعَلِّم            | muallem                   | teacher    | خَاسَانَاه         | xasanah                   | immunity       |
| لَوْح               | laux                      | blackboard | فَاخْفَا           | faxfafa                   | wealth         |

Note. All the words are used in both literary and spoken Arabic.



**Appendix B**  
**Words Used in Experiment 2**

| High-frequency word                           | Approximate pronunciation | Meaning       | Low-frequency word | Approximate pronunciation | Meaning       |
|---|---------------------------|---------------|--------------------|---------------------------|---------------|
| Transliterations of spoken words <sup>a</sup> |                           |               |                    |                           |               |
| تارتواح                                       | tartuah                   | young         | بايز               | bayez                     | broken        |
| تزانتر  | tzantar <sup>a</sup>      | in rage       | سكاج               | sakaj                     | managed       |
| كاره  | karah                     | dough cloth   | كارتوز             | kartuz                    | servant       |
| ازوك  | yzwak                     | curved        | مليفك              | mlyfak <sup>a</sup>       | cunning       |
| بجاء  | bajam                     | stupid        | مشخاتاف            | mshaxtaf <sup>a</sup>     | miser         |
| مزاميل  | mzamel <sup>a</sup>       | freezing      | جليل               | jyls                      | impertinent   |
| افاريم  | afarym                    | compliment    | جالوك              | jaluk                     | mouth         |
| بخشيش   | baxshish                  | tip           | سندخام             | sandixa                   | forehead      |
| كازام   | kazam                     | glass maker   | كاشلام             | xashlam                   | bush          |
| مككاشمش                                       | mkaxmesh <sup>a</sup>     | dry           | فانداله            | fandaleh                  | show off      |
| كارماز  | karmaz                    | kneeled       | مشاتال             | mshatal <sup>a</sup>      | distributed   |
| تابان   | taban                     | silo          | مراخدال            | mraxdal <sup>a</sup>      | untidy        |
| Words used only in literary Arabic            |                           |               |                    |                           |               |
| مقام  | makam                     | holy grave    | دباب               | dubaal                    | volcanic soil |
| ميكسار  | myjxar                    | telescope     | دجاج               | dajaj                     | hunter        |
| مударيا                                       | mudarya                   | present       | شادارات            | shadarat                  | parts         |
| داراجاه                                       | darajah                   | bicycle       | كخانوٹ             | kaxanut                   | religious     |
| ناموٹاج                                       | namuthaj                  | example       | اطباء              | atnaab                    | enlarged      |
| فاخراس  | faxras                    | content       | جهر                | jaxara                    | informed      |
| ناٹ   | naat                      | description   | نبراس              | nybras                    | flag          |
| مطالاثات                                      | muthalathat               | trigonometry  | تكنين              | taknyn                    | moderate      |
| خاسوب   | xasub                     | computer      | حدافير             | hadjafyr                  | detailed      |
| خامزه   | xamzah                    | the vowel /a/ | كاسولاه            | kabsulah                  | pill          |
| مطراميا                                       | mutaramiah                | raising       | ميدمار             | mydmar                    | range         |
| مفردات  | mufradaat                 | concepts      | أطروحة             | uutruxa                   | thesis        |
| دوره  | dawrah                    | course        | إنتقال             | yxatalaja                 | moved         |
| نظريه   | nadjariah                 | theory        | إعتباط             | aytybat                   | illogical     |
| مبتداه  | mubtadaa                  | subject       | إنتزال             | abtydal                   | sacrifice     |
| كاسره   | kasra                     | the vowel /y/ | شطان               | shatana                   | gap           |
| كاين  | kaayn                     | exist         | تصعيد              | tasyyd                    | worsening     |
| خاليه   | xalyah                    | cell          | إعتدات             | yxthead                   | followed      |
| سكون  | sukun                     | schwa         | داب                | daaba                     | interested    |
| طاقة  | takah                     | energy        | إيماء              | ymaah                     | indication    |
| عشوائي  | ashwaec                   | occasional    | مطانه              | mathana                   | bladder       |
| مسادس   | musadas                   | revolver      | مطادله             | mutadaleh                 | expert        |
| ماري  | aary                      | shrewd        | سجالان             | syjalan                   | mutual        |
| اطلاق   | atlaka                    | fire (a gun)  | تكانيا             | tikanya                   | technique     |

<sup>a</sup>Phonologically illegal in literary Arabic.

**Appendix C**  
**Additional Transliterations Used in Experiment 3**

| High-frequency word | Approximate pronunciation | Meaning     | Low-frequency word | Approximate pronunciation | Meaning          |
|---------------------|---------------------------|-------------|--------------------|---------------------------|------------------|
| زوم                 | zum                       | cycle       | زعر                | zaeer                     | active           |
| مكعبل               | mkaabal <sup>a</sup>      | spheric     | ماتكه              | matakeh                   | reason           |
| مخرك                | mxarek <sup>a</sup>       | duck (verb) | شلاتي              | shlaty <sup>a</sup>       | lazy bum         |
| مطاجين              | mtajen <sup>a</sup>       | clod        | براره              | brara <sup>a</sup>        | rejected product |
| طايش                | taysh                     | intrigued   | تلطاش              | tlatash <sup>a</sup>      | struggled        |
| مكناك               | mtanek <sup>a</sup>       | ancient     | سكانه              | sakaneh                   | cigarette ash    |
| مرفاش               | farash                    | extended    | بايخ               | bayex                     | dull             |
| مفانس               | fanas                     | disappoint  | مطارب              | mtareb <sup>a</sup>       | worn out         |
| شوف                 | shofeh                    | sight       | خوش                | xosh                      | close by         |
| مطباش               | mtabash <sup>a</sup>      | broken      | مكارساخ            | mkarsax <sup>a</sup>      | destroyed        |
| مطباداه             | tbadaa <sup>a</sup>       | shopped     | ينكالاز            | ynkalaz                   | died             |
| مطزوت               | maztut                    | thrown away | تاماس              | tamas                     | insinuated       |

<sup>a</sup>Phonologically illegal in literary Arabic.

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