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Are phonological effects fragile? The effect of luminance and exposure duration on form priming and phonological priming

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Abstract

We examined the orthographic and phonological computation of words and nonwords focusing on the pseudohomophone test in masked presentations. The priming manipulation consisted of gradually increasing or decreasing the orthographic and phonological similarity between the primes and the targets. We employed a psychophysical approach, presenting subjects with a large number of trials, while varying the parameters of exposure duration and luminance. The results suggest that phonological priming effects for brief exposure durations are robust, not fragile, and can be demonstrated for words as well as for nonwords. Moreover, the effects are not restricted to a narrow window of energy, but are revealed across a wide range of SOAs and luminance conditions. However, since the computed phonological code is initially coarse-grained, substantial phonological contrasts are required to obtain phonological effects under masked presentation.

It is now well established that phonological computation of print occurs as the rule rather than the exception. A phonological code is thus a necessary product of processing printed words, even when the explicit pronunciation of their phonological structure is not required (for a review and discussion see Frost, 1998). The debates regarding visual word recognition have thus shifted in the last decade. They do not focus on whether phonological computation occurs, but on whether the recovery of phonological information from print is the *primary, default* cognitive operation required for lexical search (e.g., Berent & Perfetti, 1995; Frost, 1998; Lukatela & Turvey, 1994a, 1994b). From this perspective, two opposing theories still provide contrasting views. The strong phonological theory assumes that the core lexical representations of the mental lexicon are phonological by definition (e.g., Frost, 1995, 1998; Lukatela & Turvey, 1994a, 1994b; van Orden, Pennington, & Stone, 1990). In contrast, dual-route theory, in its various versions, postulates a fast and efficient Orthographic Input Lexicon, suggesting that such an architecture provides a better description of the lexical system (e.g., Coltheart, Rastle, Perry, Langdon, & Zeigler, 2001; Zorzi, Houghton, & Butterworth, 1998).

The main difference between the strong phonological view and the dual-route theory, therefore, lies in the relative involvement of the orthographic lexicon on the one hand, and the nonlexical route on the other hand, in the process of word recognition. The strong phonological view assumes that prelexical computation of phonology is the first stage in processing printed information. The theory considers the product of this computation to be the initial output of the cognitive system, whereas lexical influence is assumed to be a subsequent top-down shaping of the prelexical computation, which provides a complete and phonologically

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detailed representation as a final product. A similar approach, using somewhat different theoretical constructs, is advocated by the phonological coherence hypothesis of van Orden and his colleagues (Stone & van Orden, 1994; van Orden & Goldinger, 1994; van Orden et al., 1990). This hypothesis sees visual word processing in terms of resonance between orthographic, phonological, and semantic sublexical units. Since the correlation between orthographic units and semantic features is necessarily low, and the consistency between orthographic and phonological variation is much greater than that between spelling and meaning, the computation of a coherent phonological code is the primary mechanism for reaching a final steady state and resolving inconsistencies in the lexical stimuli. By this view, orthographic codes do not provide major constraints on visual word recognition, but they do exert some influence on this process via the slower visual-semantic resonance (see for example, Lukatela & Turvey, 2000a, 2000b; for empirical support and discussion).

In contrast to these claims, dual-route theory assigns a major role to the orthographic input lexicon, as well as the direct, nonmediated connections between the letter level and the orthographic word level. For example, the most modern version of the theory, the dual route cascaded (DRC) model proposed by Coltheart and his colleagues, posits direct connections between the orthographic lexicon and the semantic system, as well as between the orthographic input lexicon and the phonological output lexicon. Thus, the DRC model regards the influence of prelexical phonological computation as *indirect*. This is because it can affect processes within the orthographic lexicon only indirectly, through the phonological output lexicon (Coltheart et al., 2001).

Perhaps the clearest difference between the two views involves the speed of phonological processing. Whereas the strong phonological theory regards prelexical phonological computation as the primary cognitive operation launched in the reading process, and considers it to be very fast (reflected in resonance theory by the speed of visual-phonological resonance), the DRC model specifically sets prelexical phonological computation to lag behind orthographic processing. The prelexical route in the DRC computational model operates only after several cycles of the simulation have taken place, and the model is structured so that lexical activation of the final phonemes necessarily precedes their prelexical activation. This architecture poses interesting constraints on the model's ability to account for lexical access occurring via fast prelexical phonological encoding.

The empirical debates between proponents of strong phonological models and dual-route models therefore revolve around experimental paradigms which focus on very early automatic processing of print and involve fast priming. This is because a necessary (although admittedly not sufficient) condition for supporting a strong phonological theory of visual word recognition is the unequivocal demonstration that phonological computation is very fast, automatic, and mandatory. Similarly, in their section "Potential problems for the DRC model." Coltheart et al. (2001) acknowledge that although in principle masked phonological priming effects could be accounted by the DRC model, "whether the model could actually simulate these effects needs to be investigated." Coltheart et al. (2001), however, correctly outline the present obstacles for such an investigation, which stem from disagreements regarding the exact effects obtained in experiments on fast priming. Since both the strong phonological theory and dual-route theory acknowledge that their major source of constraints is human behavioral data, the question at issue is what the data are and what type of constraints they impose.

Two experimental paradigms are traditionally used to examine fast automatic phonological computation: backward and forward masked priming. In the backward masking paradigm (Berent & Perfetti, 1995; Perfetti, Bell, & Delaney, 1988; Perfetti & Bell, 1991) a target word is presented for a very short duration, and followed (i.e., masked) by a pseudoword that is quickly replaced by a pattern mask. The pseudoword which masks the target can be phonemically or graphemically similar to the target, or a dissimilar control mask. The subjects' task is to report in writing what they have perceived. Depending on the specific exposure parameters, in some of the trials subjects do perceive the target word, but do not have any conscious recollection of the nonword mask. Although the nonword masks are not consciously perceived, they exert some influence on the detection of the target, since the short exposures characteristic of the masking paradigm allow the on-line processing of the nonword masks to merge with the incomplete processing of the word targets. Perfetti and his colleagues have consistently found that nonwords which were phonemically similar to the targets they masked produced better identification rates than graphemically similar controls (Perfetti et al., 1988; Perfetti & Bell, 1991; see Perfetti, Zhang, & Berent, 1992, a review). This outcome suggests that the phonological information extracted from the masks might contribute to the reinstatement of the phonological properties of the targets.

The effects obtained in backward masking are fairly small (about 5% advantage for the phonemic masks), and seem to be revealed at a narrow window of exposure duration (see Xu & Perfetti, 1999, for a discussion). Moreover, it has been suggested that the graphemic competition between different letters representing the same phoneme may result in inhibitory rather than excitatory effects (Berent, 1993). In addition, some researchers have raised doubts about the relevance of this procedure to normal reading, suggesting that the effects obtained in backward masking reflect specific strategies which induce phonemic effects (Verstaen, Humphreys, Olson, & d'Ydewalle, 1995). Similarly, Brysbaert and Praet (1992) argued that the phonemic advantage in backward masking may only be revealed when the majority of the trials include homophonic masks (but see Brysbaert, 2001, for different conclusions, as well as Berent & van Orden, 1996; Xu & Perfetti, 1999, for additional accounts for the null results of Brysbaert & Praet, 1992; Verstaen et al., 1995).

To account for these controversial inconsistencies, Gronau and Frost (1997) proposed that the probability of obtaining phonemic effects in backward masking depends on the phonological contrast between phonemic and graphemic masks. Gronau and Frost argued that the representations computed in brief exposures are coarse-grained and not detailed enough to capture fine phonetic differences. Thus, only large phonological contrasts between experimental conditions reveal phonological effects. These conclusions were further reinforced by a subsequent study which demonstrated that the probability of detecting a masked target depended on both the orthographic and the phonological overlap between the target and the mask (Frost & Yogev, 2001).

An even more inconsistent pattern of results in phonological processing emerges in the forward masking paradigm. In the three-field masking technique, developed by Forster and Davis (1984), a pattern mask is presented before the prime, with a very brief temporal interval between the onset of the priming stimulus and the subsequent target stimulus. Because the prime is presented briefly, and is masked by a combination of forward and backward masking (the latter coming from the target), the prime itself is usually unavailable for report. This feature satisfies the criterion for a covert phonological manipulation that does not induce overt phonological strategies. In the four-field masking procedure the first mask is presented before the prime, and the second mask is inserted following the target. Exposure duration is set according to individual thresholds so that target identification occurs about 50% of the time (Evett & Humphreys, 1981; Humphreys, Evett, & Quinlan, 1990). The experimental task is not lexical decision but target identification. As in the three-field masking, however, subjects are not aware of the prime in this procedure.

Experiments using three- or four-field forward masking revealed one of the most robust effects in visual word recognition: form-orthographic priming (Forster, Davis, Schoknecht, & Carter, 1987). Form priming occurs when the primes and the targets share most of their letters in the same positions. In general the facilitation obtained with masked priming is claimed to reflect a *transfer* effect. The result of processing the prime is transferred across to the target. This transfer is made possible when the primes and targets have overlapping orthographic structures (see Forster, 1987; for a discussion). Using the four-field masking technique, Humphreys et al. (1990) showed that priming effects increased or decreased as a function of the number and position of the letters shared by the primes and the targets, and that both specific and relative positions of letters affected priming. Humphreys et al. (1990) therefore suggested that the processing mechanism provides an *orthographic* description that is parsed according to letter cluster representations within the word. Form priming, thus occurs when primes and targets share a similar orthographic description.

Interestingly, in contrast to backward masking, few studies have reported phonological priming effects with forward masking. Using the four-field masking technique, Lukatela and Turvey reported significant phonological priming in the naming task (Lukatela & Turvey, 1994a, 1994b). These findings could, however, be criticized on the grounds that they do not necessarily reflect the process of visual word recognition, since naming explicitly requires the computation of a phonological structure. By this argument, phonological priming should be demonstrated in tasks that do not specifically entail the retrieval of the word's phonology, such as the lexical decision task. Shen and Forster (1999) showed that while pseudohomophone priming is clearly obtained in the naming task with a given set of Chinese characters, the same set of characters does not produce priming effects in the lexical decision task. It could be argued that the absence of phonological effects in the logographic Chinese cannot be generalized to alphabetic orthographies, but Ferrand and Grainger (1992) found no effects of phonology in brief SOAs in lexical decisions in the alphabetic French. Failure to obtain phonological priming under masked presentation was also reported by other investigators in English (e.g., Davis, Castles, & Lakovidis, 1998). Such a null-effect pattern has often been taken as evidence against the strong phonological theory.

One prominent exception to null effects of phonology in forward masking is a recent study by Lukatela, Frost, and Turvey (1998). We will describe this study in detail, since it generated several replication failures, which led to considerable debate in the scientific community concerned with phonological processing. These debates were mostly oral rather then printed, because many journals, as a general policy, tend not to publish failures to replicate.

The Lukatela et al. (1998) study

The Lukatela et al. study was designed to examine *The Pseudohomophone Test* in masked priming using lexical decisions. The test monitors the facilitation induced by an unidentifiable homophonic nonword on the recognition of a subsequent visually presented target (Humphreys, Evett, & Taylor, 1982; Lukatela & Turvey, 1994b). This manipulation is considered to be a critical test for the role of phonology in visual word recognition, because the facilitation induced by the nonword prime is necessarily prelexical, and the time course involved in this paradigm is very brief. If facilitation in forward masking experiments reflects a transfer effect, in which the computations involved in processing the prime are transferred to the target, then any additional priming induced by homophonic nonwords over orthographic controls demonstrates that these computations are primarily phonological. Note that homophonic nonwords are compared to nonhomophonic nonwords which overlap orthographically with the target to the same extent. Finally, if the test should reveal positive results at very brief exposure durations under masked presentation, it would suggest that the prelexical computation of phonology is launched automatically immediately following letter detection and poses early constraints on lexical access.

Several studies have employed the pseudohomophone test and obtained mixed results. Davis et al. (1998) found no advantage of pseudohomophones primes like *wosh* over orthographic controls like *wesh* for target words like *WASH* using an SOA of 57 ms. However, since in this study Davis et al. did not obtain orthographic form priming either (i.e., *wesh–WASH* was no better than *mirt–WASH*), these findings are difficult to interpret. In contrast to Davis et al. (1998), quite a few other studies reported positive results using the pseudohomophone test, but with exposure durations of 40–50 ms and over. For example, Perfetti and Bell (1991) found a pseudohomophone advantage in English with nonword primes at an SOA of 40 ms. Similar results were reported in French by Ferrand and Grainger (1992), who demonstrated phonological priming effects only with a fairly long prime durations of 64 ms, and not in the shorter exposure duration of 32 ms. These results were further extended in a follow-up study by Ferrand and Grainger (1993), who suggested that phonological priming effects begin to emerge only at exposures of 40–50 ms. In the same vain, Grainger and Ferrand (1996) contrasted pseudohomophone primes with nonhomophonic primes at an SOA of 43 ms, reporting significant phonological priming effects in both the lexical decision task and the perceptual identification task. Finally, Brysbaert (2001) found a pseudohomophone effect in Dutch with an exposure duration of 43 ms, but not with 29 ms. These findings are, to some extent, in agreement with the DRC model, since prelexical phonological facilitation was consistently found to lag behind orthographic facilitation, and could not be obtained at shorter SOAs.

In contrast to these studies, Lukatela et al. (1998) reported a positive result of the pseudohomophone test with even shorter exposure durations. What Lukatela and his colleagues did was to examine whether nonword primes like *klip* speed lexical decisions to targets like *CLIP*, compared with nonword primes like *plip*. As *klip* and *plip* both differ from *CLIP* by a single letter, any additional priming induced by *klip* must be purely phonological. Moreover, given the masked exposure of the nonword prime, its effect on processing the target cannot be attributed to a conscious strategy adopted by the subjects. Finally, since the phonology computed for a nonword prime like *klip* is necessarily prelexical, any impact it might have on detecting the subsequent word target *CLIP* would imply that the phonological computation involved in identifying the target word is prelexical as well. All of these conclusions are in perfect accord with the strong phonological theory.

Lukatela et al. reported a 22 ms advantage for *klip* over *plip* primes at an SOA of 57 ms. However, in a subsequent experiment, where the luminance of the mask was manipulated, they also found a significant 14 ms advantage for *klip* primes at an SOA of 29 msec. As stated above, the report of these findings generated subsequent unsuccessful attempts to replicate the results in a few laboratories (e.g., Coltheart and Woolams, unpublished manuscript; Forster & Mahoney, unpublished manuscript). Following discussions among these researchers, Lukatela et al. (1998) clarified (Footnote 2) that "for unknown reasons, the dim lighting proves to be crucial. Pilot work failed to find any differences, at very brief prime durations, among full and partial phonological primes under the condition of high illumination in our research room which had previously served as an office. It was only by reducing the room illumination to that provided by a single desk lamp at floor level that we could obtain reliable priming differences." Given the theoretical implication of the pseudohomophone test for dual-route theory, Coltheart et al. (2001) discussed this issue at length in their recent exposition of the DRC model. They stated, however, that: "it seems essential to discover what the unknown reasons are for the need to have very dim lighting to obtain the *klip–CLIP* effect before one would attempt to simulate this result." The present study aims at doing exactly that.

Theoretical ramifications

The investigation of the *klip–CLIP* effect is by no means concerned with simply finding out who is right or wrong in the debate about the pseudohomophone test. Rather, we suggest that the issue of phonological priming in masked presentation raises important theoretical and methodological questions that need to be elucidated.

In support of Lukatela et al's. interpretation, it is well established that even high-level cognitive processes in visual word perception are energy-dependent and that effects of masking interact with luminance conditions (e.g., Michaels & Turvey, 1979). More specifically, psycholinguistic processes are not immune to energy manipulations, and factors such as the inter-stimulus-interval interact with the relative energy of the mask, the prime, and the target events (e.g., Kinsbourne & Warrington, 1962a, 1962b; Turvey, 1973). This may have consequences for the priming effects, so that priming obtained with a specific set of presentation parameters may not be obtained with another set. Luminance, as well as SOA, are obviously important parameters of presentation, so they are likely to have consequences for priming. More importantly, light adaptation necessarily influences performance, and consequently, careful consideration of lighting conditions is of substantial significance in experiments involving brief exposures. However, what underlies the controversial footnote of Lukatela et al. (1998) is the claim that phonological activation can be detected only at a certain window of energy. In this view, experimenters often obtain null effects of phonology under masked presentation (e.g., Davis et al., 1998) simply because they missed that window.

However, the theoretical complications that emerge from this view for the strong phonological theory advocated by Lukatela et al., are quite substantial. The first complication involves the descriptive adequacy of the theory. There is no a priori commitment to a specific window of energy in which effects of phonology will be revealed. The second complication concerns its explanatory adequacy. There is no clear explanation as to *why* phonological effects are restricted to a specific narrow window of energy. Finally, Lukatela's argument resembles a Pyrrhic victory. It may perhaps locally account for the numerous replication failures, but in the long run it would undermine the main claim of the strong phonological theory. For if phonological effects are so fragile, perhaps they are not that central in imposing constraints on lexical access as the strong phonological theory predicts (Frost, 1998).

A close examination of the Lukatela et al. study reveals several possible shortcomings of their experiments. First, as in many experiments in this domain, the critical experimental conditions yielded about 500 data points. A possible type 1 error needs to be considered, especially given the subsequent numerous replication failures. More interesting, however, is the possibility of an alternative theoretical explanation. An important feature of the Lukatela et al. study is that *all* the stimuli contained C/K alterations, where the consonant C as in *CLIP* was always replaced by K. What may be narrow then is not the window of energy in which the phonological effects are obtained, but the range of the phonology.

Phonological manipulation and the impoverishment of phonological codes

A major theoretical construct of the strong phonological theory is the impoverishment of phonological encoding (Frost, 1998). As Frost points out, the initial contact with the lexicon occurs through an access representation that is impoverished and coarse-grained (*the minimality constraint on lexical access*, p. 79). The minimality constraint is a basic tenet of the strong phonological theory because it provides an account for null effects of phonology in the lexical decision task. There is however, substantial empirical support for it from experiments using fast priming.

Using backward masking, Gronau and Frost (1997) showed that subjects' performance with graphemic masks, which alter one consonant in the target, was similar to their performance with fully homophonic masks. In contrast, if the altered letter in the graphemic mask replaced a vowel letter by a consonant letter, resulting in a more substantial change of the target's phonological structure, detection rates deteriorated significantly relative to the homophonic mask. Thus, it seems that the phonological code computed from the nonword mask was not fine enough to detect a single consonantal change in the target, but was nevertheless sensitive in detecting more salient phonological changes (i.e., consonant + vowel). Similar finding have been reported by Frost and Yogev (2001), again in Hebrew, and by Brysbaert (2001) in Dutch. Brysbaert directly contrasted two sets of stimuli, one with one mismatched phoneme between target and mask, and the other with two mismatched phonemes. Whereas no effects were found for the first set, clear significant phonemic effects were found for the latter set (but see Shen & Forster, 1999, for different results and conclusions).

Turning to the *klip–CLIP* effect, the results from backward masking in Hebrew or Dutch predict failure in the pseudohomophone test when a single consonant is altered. If the phonological code computed from the nonword mask is coarse-grained without apparent differentiation between consonants, a similar representation will be initially computed for *klip* and *plip*. Thus, no additional facilitation is expected for *klip* over *plip* primes. To complicate things even further, all alterations in the Lukatela et al. study were initial letter alterations. These experimental features may create problems of ecological validity. Not only is the phonological manipulation provided by altering a single consonant too weak, but also the ongoing repetition of this manipulation may have led the subjects to detect it. Unfortunately, given the characteristics of English orthography, especially its very few homophonic letters, these caveats could not have been circumvented. To alleviate this problem to some extent, Lukatela et al. introduced some fillers into the experimental list. However, it remains possible that the demand characteristics of the experiment were transparent to the subjects.

A psychophysical approach to fast priming

The present study aims at addressing these methodological and theoretical issues. Our experiments thus follow the suggestions specified by Coltheart et al. (2001), employing a psychophysical parametric approach to map the exact conditions under which, if at all, phonological priming can be obtained in the forward masking paradigm. The theoretical perspective that governed our investigation stems from the minimality constraint on the phonological code. We manipulated orthographic and phonological structure independently, creating increased orthographic and phonological dissimilarity with the target, while altering luminance and exposure duration parametrically.

Our study took advantage of the unique properties of Hebrew orthography. Hebrew is considered a deep orthography (Frost, Katz, & Bentin, 1987; Katz & Frost, 1992), in which letters mostly represent consonants while most of the vowels can optionally be superimposed on the consonants as diacritical marks ("points"). In the present context, the first relevant feature of the Hebrew orthographic system is that it includes 12 homophonic letters: two letters representing the phoneme /t/, two representing the phoneme /k/, two representing the phoneme /x/, two representing /v/, two representing /s/, and two representing the glottal stop /ç/. These letters depicted salient phonetic differences in ancient Hebrew, but they are no longer apparent in modern Hebrew. The second interesting feature of Hebrew is that, although the diacritical marks representing vowels are omitted from most adult reading material, some of the vowels (mainly /o/, /u/, /i/) may be represented in print not only by points but also by letters. (The Hebrew alphabet is presented in Appendix A.) These two features of Hebrew orthography allow much richer phonological manipulations for conducting the pseudohomophone test. First, not being restricted to C/K alterations, a large variety of pseudohomophones can be created by interchanging several consonantal letters. Moreover, within a given word, more than one letter can be altered. Finally, substituting vowel letters by consonants and vice versa, in contrast to consonant letters by consonants, creates a linear continuum of phonological dissimilarity between primes and targets. This manipulation allows a multiple verification of the pseudohomophone test, and also provides a direct examination of the minimality constraint. If fast phonological computation does not occur in forward masking, then all the phonological differences in the various priming conditions should have no effect on subjects' performance. If, however, phonological computation is a mandatory process resulting in a coarse-grained phonological code, then fine phonological differences between primes and targets will have no effect on target detection, whereas larger differences will.

We employed two versions of masked priming. The first was the original three-field procedure, while the second consisted of a continuous display of the targets, but involved the online substitution of some of their letters. In each version two sets of identical experiments were conducted, one manipulating luminance, the other exposure duration. Our view of luminance and exposure duration is that they are interchangeable within the range of parameters we applied (Bloch's law; see Hood & Finkelstein, 1986). Since cognitive events in visual word recognition are energy dependent, both luminance and exposure time determine the amount of energy that is provided to the cognitive system for the perception and identification of the distal stimulus. Whereas luminance monitors energy directly, exposure duration monitors energy through summation across time. Hence, these two procedures are operational replications of each other. In each of our experiments four levels of luminance or four levels of exposure time were investigated.

The psychophysical approach was implemented by presenting each participant with each target word again and again in all the experimental conditions. Thus, each participant was presented with hundreds of trials that differed from one another in the amount of energy (various levels of luminance or exposure duration) or the phonological or orthographic dissimilarity of the primes to the targets. This experimental procedure allowed the use of a full within-subject within-stimulus design, in which subject and item variability would not interact with the different experimental conditions. More important, it allowed us to gather about 20,000 data points in each experiment. Such a volume of data points ensured a stable parametric mapping of the possible interactions between phonological and orthographic priming and exposure parameters. It also reduced the probability of obtaining an accidental type I error due to the idiosyncratic characteristics of a small sample of data points.

In general, the psychophysical approach is common in the field of visual perception, and much less so in word recognition. This is because, unlike responses to simple visual stimuli such as line orientation, words induce repetition effects which stem from the properties of lexical architecture. We borrowed some principles of the technique for our investigation so we could benefit from the stability of repeated measures, while bringing repetition effects to a minimum, as described in detail in the method sections.

Experiments 1a and 1b

Experiments 1a and 1b used the typical three-field forward masking technique, the one used in the lexical decision task in the Lukatela et al. study. Experiment 1a manipulated exposure duration parametrically with 4 levels of SOA between primes and targets (10, 20, 30, and 40 ms), while luminance was kept constant (7.0 cd/m^2). Experiment 1b manipulated luminance parametrically (0.75, 1.5, 3.0, and 7.0 cd/m^2) while SOA was kept constant (40 ms).

In both experiments there were three levels of orthographic similarity and three levels of phonological similarity between primes and targets, allowing an incremental alteration of phonological and orthographic form. Thus, effects of increased phonological similarity/dissimilarity could be assessed when orthographic structure was kept constant, and vice versa. This allowed a detailed investigation of the minimality constraint on lexical access, mapping the fine-tuning of orthographic and phonological computation during visual word recognition.

Methods

Subjects

Seventy-nine participants from the Hebrew University, all native speakers of Hebrew, participated in the experiment. Thirty-nine were tested in Experiments 1a and 40 in Experiment 1b.

Stimuli

Forty-eight target Hebrew words, and 48 target nonwords, three to five letters long, containing three to six phonemes, were employed. The stimuli were presented unpointed. All target words, however, were phonologically unambiguous, since they could be read as meaningful words in only one way.[1] The nonwords were constructed by replacing one or two letters of the target words.

Each target, word or nonword, could be primed by six possible primes: (1) an identity prime, a condition that provided the baseline for maximal facilitation in our exposure parameters; (2) a homophonic prime in which one consonant letter of the target was replaced by the homophonic letter representing the same phoneme, hence the "homophonic-one-letter-different condition;" (3) a homophonic prime in which two consonant letters of the target were replaced by two homophonic letters, hence the "homophonic-two-letters-different condition;" (4) a prime in which one consonant letter was replaced by another letter representing a different consonant, hence the "one-phoneme-different condition;" (5) a prime in which one consonant letter was replaced by a vowel letter or vice versa, creating a prime differing from the target by two or three phonemes, hence the "two–three-phoneme-different condition;" Finally, (6) a control condition, in which the primes differed from the targets in most of their letters. This last condition served as the baseline from which all priming effects were calculated.

The six conditions allowed multiple independent tests of the effects of orthographic and phonological similarity. The impact of orthographic structure could be assessed by comparing the three conditions in which the primes were homophonic with the target, thereby preserving its phonology, in either being identical to the target, or different in one or two letters. These were the identity condition, the homophonic-one-letter-different condition, and the homophonic-two-letters-different condition. In parallel, the impact of phonological structure could be assessed by comparing the three conditions in which the graphemic overlap of the primes with the target was identical, but the primes differed from the targets in zero, one, or more phonemes. These were the homophonic-one-letter-different prime, the one-phoneme-different-prime, and the two–three-phoneme-different prime. These three primes differed from the target in a single letter, but depending on the specific letter which was altered, their phonology was either identical, similar, or dissimilar to that of the target. The position of the substituted letters within the target words was balanced so that they could be initial, middle, or final. Table 1 presents examples of primes and targets in the six experimental conditions which were the basis for our study.

Design

Our psychophysical design presented each subject with each word in each priming position, with exposure conditions varying in each trial. The six priming conditions and the four exposure conditions created a matrix of 24 cells. Twelve words and 12 nonwords were randomly assigned to each cell for each subject, creating $24 \times 24 = 576$ experimental trials. These were divided into three blocks of 192 trials each. Note that each word and nonword appeared 6 times for a given subject in the experimental session, once in each priming condition. Of the six presentations, four were in the different exposure conditions, and the additional two presentations were

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[1] Because the printed consonants can, in principle, take any of the 5 vowels of Hebrew, a nonword mask can be read in more than one way. Nevertheless, as all Hebrew words are composed of a root morpheme and an infixed phonological word pattern, the possible readings of a consonant string are constrained by the permissible word patterns of Hebrew and their relative frequency.

The fact that Hebrew print does not include vowel marks also has implications for neighborhood density measures. On the average, Hebrew words are shorter, and many words have a large number of orthographic neighbors. Recent experiments from our laboratory demonstrate that, in contrast to English, neighborhood density does not affect form priming in Hebrew (Frost, Kugler, Deutsch, & Forster, 2001).

Table 1
Primes and targets in the six experimental conditions

	Identity	Homophonic one-letter-different	Homophonic two-letters-different	One phoneme different	Two phoneme different	Control
Prime	כפית	קפית	קפיט	כפיז	כפזת	זבלד
Printed form	KPIT	QPIT	QPI*t*	KPIZ	KPZT	ZBLD
Phonologic form	/kapit/	/kapit/	/kapit/	/kapiz/	/kapezet/	/zabład/
Target	KPIT כפית	KPIT כפית	KPIT כפית	KPIT כפית	KPIT כפית	KPIT כפית

t and T, Q and k represent the homophonic letters for /t/ and /k/, respectively. Hebrew is read from right-to-left so the final letter is the left-most letter. The vowel /a/ is not represented in unpointed Hebrew. The vowel /i/ is represented by the letter "י"

equally balanced so that, across all subjects, each of the 24 matrix cells had an equal number of trials.

Obviously, the repetition of target words for a given subject creates repetition priming effects. This was not a *systematic* confound that interacted with specific conditions. Nevertheless, to minimize the error variance induced by repetition, each target word was initially presented twice to a given participant as dummy trials. Thus each subject began the experiment by making lexical decisions to $2 \times (48 + 48) = 192$ trials which did not enter the statistical analysis. The aim of the dummy trials was to bring the impact of repetition to an asymptote. Only then were response times recorded. All in all, each subject responded to $192 + 576 = 798$ trials.

Procedure and apparatus

The experiment was conducted on an IBM Pentium III computer, with a 17 in. Sony monitor. Graphics was presented using a VSG graphics card (made by Cambridge Research Systems), which is designed for accurate control of stimulus contrast and timing. Each trial consisted of three sequential visual events. The first was a forward mask consisting of a row of eight hash marks that appeared for 500 ms. The mask was immediately followed by the prime with variable exposure parameters which differed in Experiments 1a and 1b. The prime was then replaced by the target which remained on the screen until the participant's response.

Experiment 1a

There were four prime exposure durations: 10, 20, 30, and 40 ms. The luminance of the print was 7.0 cd/m^2 in all trials, whereas the luminance of the screen was less than 0.01 cd/m^2. Thus, the contrast in all conditions was close to 1.0. The room was totally dark.

Experiment 1b

There were four luminance conditions: 0.75, 1.5, 3.0, and 7.0 cd/m^2. The luminance of the screen was again less than 0.01 cd/m^2, so that the contrast in all conditions was close to 1.0. Exposure duration for all trials was 40 ms. The room was totally dark.

All visual stimuli were centered in the viewing screen and were superimposed on the preceding stimuli. Although only one Hebrew square font was employed, two versions of this font, which differed in their relative size, were used. Targets were always presented in the larger font (25% larger than the primes). This resulted in the complete coverage of the primes by the targets, and also made the primes and the targets physically distinct stimuli.[2]

Each participant completed the experiment in a single session. However, the 798 trials were divided into two dummy blocks with 96 trials each, and three experimental blocks with 192 trials each. After each block the participants were allowed to rest as needed before initiating the next block by themselves. The order of trials for each participant was random. The experiment lasted about 1 h.

Results

RTs for correct responses in the experimental conditions were averaged across participants. Within each participant, RTs that were outside a range of 2 *SD*s from his/her mean were trimmed. The effect of outliers was minimized by establishing cutoffs of two standard deviation units above and below the mean for each participant. Any RTs exceeding these cutoffs were replaced by the appropriate cutoff value. Trials on which an error occurred were discarded. This procedure was repeated in all of the following experiments. Outliers and errors accounted for about 5% of the trials.

Given the very large number of data points assembled in our study (21,152 data points in Experiment 1a, and 21,718 data points in Experiment 1b), simple significance tests are no longer informative, as even very

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[2] In English the separation of primes and targets is often achieved by using upper case and lower-case scripts. Although Hebrew has two forms of script (regular print and cursive), the cursive script is hardly ever used in print, and we therefore adopted the manipulation of size rather than form.

small effects are statistically reliable with such extremely large *N*s. Therefore, rather than using traditional ANOVAs, we will focus on the *pattern* of priming across experimental conditions, reporting the critical difference score above which all priming effects are significant. *F* values for the effects as well as the means, *SD*s, and error rates of each of the 24 cells are presented in Appendices B and C. Note that in both Experiments 1a and 1b the error pattern seems erratic. However, since there was no apparent consistent pattern of speed-accuracy trade-off in specific experimental conditions across SOA or luminance levels, we will focus in our analyses on the latency data.

Experiment 1a–SOA

Fig. 1 presents the effects of priming in the six experimental conditions, averaged across all exposure durations, while Fig. 2 presents the individual effects in each SOA. Considering Fig. 1 first, the most striking result is the almost identical pattern of priming obtained for words and nonwords. We will elaborate on this finding at length in the General Discussion. The figure reveals a linear effect of orthographic structure. Although the homophonic-one-letter-different, and the homophonic-two-letters-different primes had the same phonemic structure as the identity prime, the alteration of letters slowed response times so that each substituted letter increased lexical decision time additively. This result is in accordance with the findings of Ferrand and Grainger (1994), and Grainger and Ferrand (1996), who showed a similar orthographic effect in French.

More interesting however is the effect of phonological structure. Three independent contrasts can be used in our design for conducting the pseudohomophone test. The first is the homophonic-one-letter-different condition contrasted with the one-phoneme-different condition. This is, in fact, the original *klip–plip* comparison used in the Lukatela et al. (1998) study. The advantage of *klip*-like over *plip*-like primes was very small, +6 ms for words and +5 ms for nonwords. The Fisher's critical difference for significance when all data points are pooled together was about 5.1 ms ($p < .05$). Thus, this effect is not only extremely small but also only marginally significant.

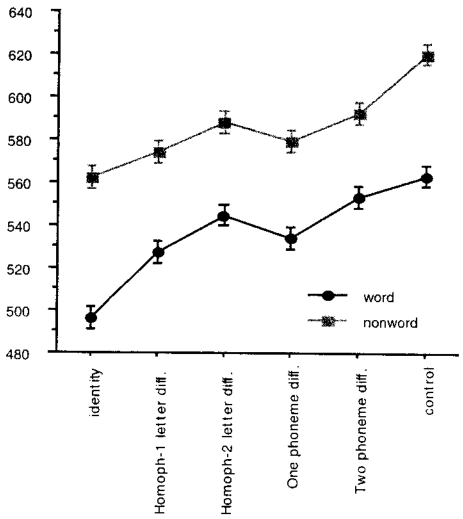

Fig. 1. The effect of six priming conditions across all exposure durations.

Our experiment, however, allowed two additional explorations of the pseudohomophone test. The next contrast to be considered is the one-phoneme-different condition vs. the two–three-phoneme-different condition. Both primes in these conditions differed from the target by one letter, but the former altered its phonology by a single consonant, whereas the latter altered its phonology more dramatically. The phonological effect in this comparison was much more pronounced, +19 ms for words and +14 ms for nonwords. The final version of the pseudohomophone test is the comparison between the homophonic-one-letter-different and the two–three-phoneme-different primes. Again, both differed from the target by a single letter, but the former was homophonic as *KLIP* was, whereas the latter altered the phonology by two to three phonemes. The phonological effect in this comparison was exceedingly large, as it summed the previous effects together, +25 ms for words and +19 ms for nonwords.

Turning now to the effects of orthographic and phonological priming across SOAs, Fig. 2 describes how these effects unfold with exposure duration. As 10 ms constitutes a very brief exposure, the main reliable effect for both words and nonwords appears to be the slower latencies in the control condition as compared to all other conditions. The graphs for words and nonwords also seem to diverge, reflecting the noise that is apparent with such brief exposures. However, with even 20 ms of exposure, the priming pattern already begins to resemble the general pattern observed in Fig. 1. At 30 ms the curves observed for words and nonwords are virtually parallel, demonstrating that the priming effects are almost identical for words and nonwords, as described above. With the longer SOA of 40 ms there seems to be a slight divergence from the parallel word-nonword priming pattern, but again, effects of both orthographic and phonological similarity are clearly apparent.

With regard to the *klip–CLIP* effect at each SOA, the results suggest that the facilitation induced by a single consonantal difference was erratic. It was negative or zero in the first two SOAs, and slightly larger for both words and nonwords in the SOA of 30 ms. With an SOA of 40 ms, however, facilitation became larger for words, but turned negative for nonwords. In contrast, the larger phonological contrasts produced robust facilitation which was consistent for both words and nonwords.

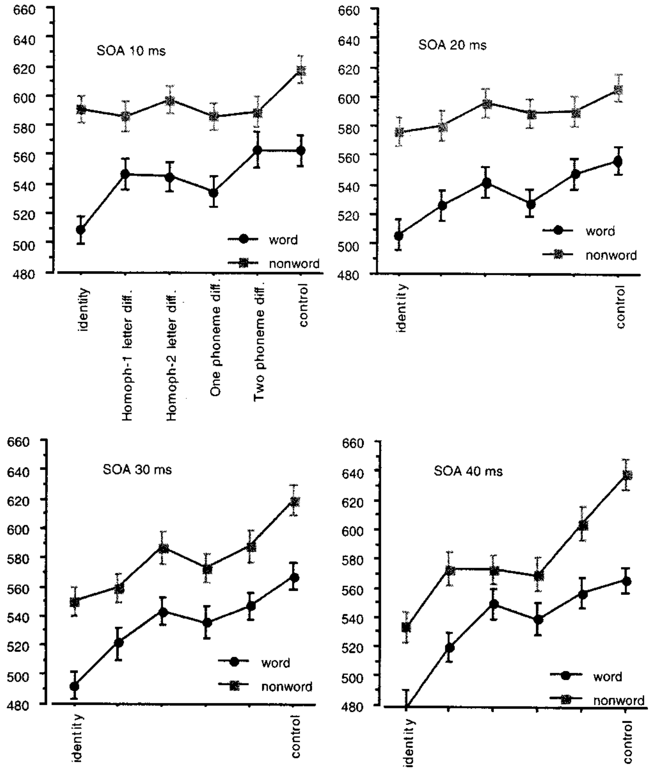

Fig. 2. Effect of the six priming conditions at 10, 20, 30, and 40 ms SOA.

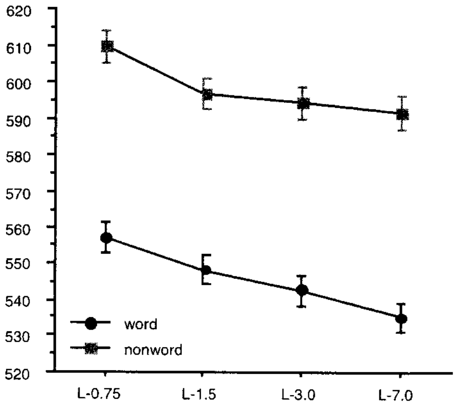

Fig. 3. The effect of luminance on lexical decision latencies.

This finding demonstrates that the outcome of the pseudohomophone test is best determined by the phonological contrast between primes and targets, rather than exposure duration. Thus, unequivocal evidence for phonological computation can be demonstrated as long as the primes and the targets differ by more than one consonant. Finally, we should note that some SOAs produced hyper-priming effects in the identity priming condition (facilitation exceeding the prime SOA). We will refer to this phenomenon in General discussion.

Experiment 1b–luminance

Fig. 3 examines the effectiveness of the luminance manipulation with our chosen luminance parameters across all priming conditions. As expected, latencies decreased linearly when luminance increased, although the effect seems to be more pronounced for words. This generally validates the experimental procedure.

Fig. 4 presents the effects of priming in the six experimental conditions, averaged across all luminance levels, while Fig. 5 presents the individual effects in each level of luminance. The most striking outcome in Fig. 4 is the almost identical pattern of results obtained in manipulating SOA and luminance.

As in Experiment 1a, there was a linear effect of orthographic structure, and each letter alteration slowed subjects' responses additively when phonology was kept constant. The interesting result, however concerns phonological computation. The *klip–PLIP*-like pseudohomophone test (the difference between the homophonic-one-letter-different and the one-phoneme-different primes) revealed a small effect of +9 ms for words and +4 ms for nonwords, with an average effect of +6.6 ms. As Fisher's critical difference for significance ($p < .05$) was

5.2 ms, this again constitutes a marginal, seemingly unstable effect. The pseudohomophone tests involving larger phonological contrasts, however, were very robust. The difference between the one-phoneme-different and the two–three-phoneme-different primes was +16 msec for words and +15 ms for nonwords. The most extreme contrast between the homophonic-one-letter different and the two–three-phoneme different primes thus provided a summed effect of +25 ms for words and +19 ms for nonwords.

Fig. 5 provides an insight into the stability of the orthographic and phonological priming effects in the various luminance conditions. As with the SOA manipulation, effects tended to stabilize with increased luminance, with a slight divergence of priming patterns for words and nonwords at the highest level of luminance.

Regarding the *clip–KLIP*-like priming effect, it was even more erratic than that revealed in Experiment 1a. For the ascending levels of luminance, the *clip–KLIP* effect was +9, +1, 0, and +13 ms for the words, and +2, +13, +7, and −5 for the nonwords at the four levels. Hence, it fluctuated in an unpredictable manner when luminance increased incrementally. In contrast, the

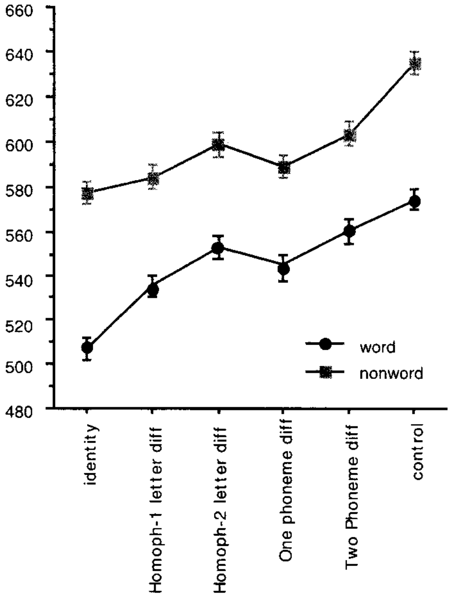

Fig. 4. The effect of six priming conditions across all luminance levels.

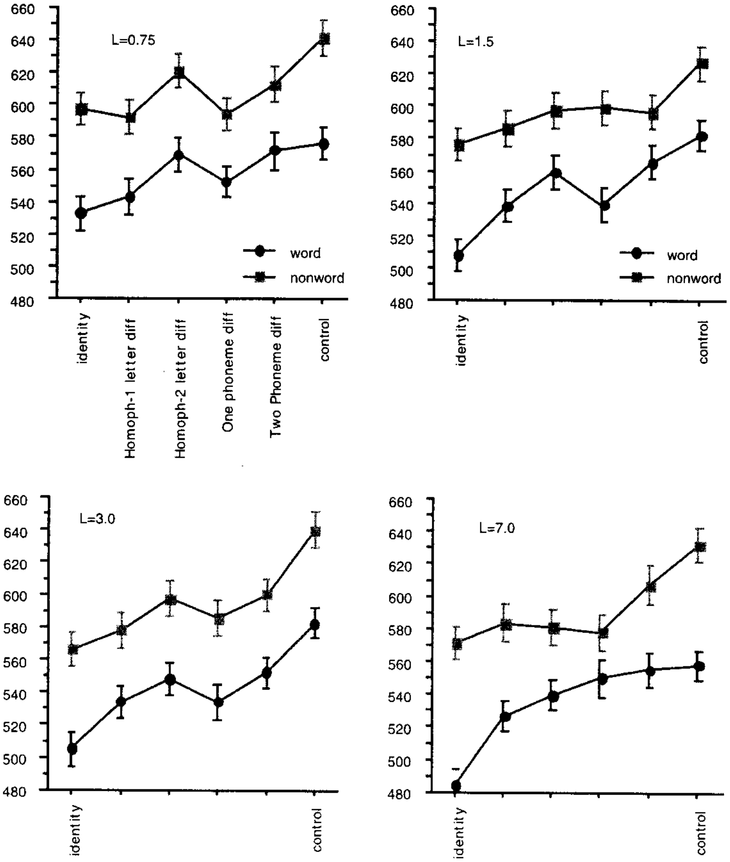

Fig. 5. Effect of the six priming conditions at 0.75, 1.5, 3.0, and 7.0 cd/m^2.

larger phonological contrasts yielded robust phonological priming at every luminance level.

Discussion

Four immediate conclusions can be drawn from our first set of experiments. First, increasing changes in the orthographic structure affect performance almost linearly. This outcome is not surprising, and was previously reported by Ferrand and Grainger (1994), and Grainger and Ferrand (1996). Although Grainger and Ferrand (1996) concluded that this finding contradicts the phonological encoding hypothesis (p. 625), we suggest that the effects of orthographic dissimilarity are independent of the effects of phonological dissimilarity. Obviously phonological computation is contingent on the accurate registration of orthographic information from the visual array. The strong phonological view suggests that the specific orthographic structures that initiated the process of phonological computation determine the final outcome of semantic meaning activation. Thus, the greater inhibition caused by increased orthographic dissimilarity is predicted by the theory (see for extensive discussion Frost, 1998; Lukatela & Turvey, 2000a; van Orden & Goldinger, 1994, for parallel arguments of the phonological coherence theory).

Second, manipulating exposure duration and luminance in priming experiments produces similar results. Both procedures monitor the amount of energy provided for the perception and processing of printed information by the cognitive system, and can thus be interchanged. Third, the suggestion that phonological manipulations in fast priming are fragile, and can be found only in narrow windows of energy, is probably wrong. Phonological manipulations are robust and can be revealed across a wide range of exposure parameters. Finally, what determines the outcome of phonological manipulations in fast priming such as the pseudohomophone test, is the window of phonology, not energy. Although we employed only four levels of exposure duration and luminance, our results show that if the experiment involves a salient phonological manipulation, then priming effects can be revealed under masked presentation on almost any of these levels. In contrast, if the experimental design involves fine phonetic manipulations, then small and often unreliable priming effects are found. This conclusion is in accordance with the minimality constraint of the strong phonological theory.

Experiments 2a and 2b

Experiments 2a and 2b introduced a different paradigm involving brief exposure durations with the goal of examining orthographic and phonological computation in another experimental context. Any interpretation of priming effects hinges on the implicit tenets characteristic of the specific priming paradigm. Our aim in the following experiments was to seek another validation of our conclusions regarding the strong phonological theory, by demonstrating that our findings are independent of the idiosyncratic properties of the masked priming procedure.

Our technique consisted of presenting the targets continuously on the screen, and substituting one or two letters of the targets after a very brief exposure time to measure the cost of letter alteration. The substituted letters reflected exactly the same six experimental conditions employed in the previous experiments. For example, in the one-letter-homophonic condition, subjects were first presented with the target, which was spelled as the prime in the previous experiment (e.g., *capit*). Following the various SOAs, the homophonic letter C was replaced by the correct target letter K (e.g., kapit). By the same principle, targets in the identity condition were simply presented longer given the SOA, while targets is all other conditions were initially presented with one wrong letter or more. These letters were replaced by the correct ones after varying SOAs in Experiment 2a, or at a constant SOA but with different luminance levels in Experiment 2b.

These seemingly simple procedural changes created a different context for interpreting the effects of the various experimental conditions. In contrast to the previous experiments in which *priming* effects were computed by measuring facilitated performance relative to the control condition, the relevant dependent measure in our paradigm was the *inhibition* caused by letter alteration compared to the identity condition. Since the identity condition meant a continuous and unaltered presentation of the target, what we measured was the *cost* of altering one homophonic letter, two homophonic letters, one letters with one phoneme change and one letter with two-to-three phoneme changes in the target compared to no alteration at all.

From a pure orthographic perspective, the more letters that are replaced the worse performance should be. Letter position might affect performance, but not the phonological status of the replaced letters. In contrast, from the strong phonological theory perspective, if the initial presentation of the printed stimulus involves mandatory fast phonological computation, when the number of replaced letters and their position are kept constant, the phonological status of the replaced letter should affect performance. This is because the phonological structure computed from the initially presented letters would need to be adjusted, given the subsequent letter alterations. Again, if the phonological code is initially coarse-grained and impoverished, replacing one consonantal letter will have little effect on target recognition, whereas more significant phonological changes will result in greater inhibition.

Methods

Subjects

Seventy-seven subjects from the Hebrew University, all native speakers of Hebrew, participated in the experiment. Forty were tested in Experiment 2a and 37 in Experiment 2b. None of the subjects had participated in the previous experiments.

Stimuli and design

These were identical to those in the previous set of experiments.

Procedure and apparatus

Each trial consisted of three visual events. The first was a forward mask consisting of a row of eight hash marks that appeared for 500 ms. The mask was immediately followed by the prime which was printed with zero, one, two, or more altered letters depending on the experimental condition. In Experiment 2a, the initial printed form was presented in four exposure durations: 10, 20, 30, and 40 ms. The luminance of the print was 7.0 cd/m^2 in all trials, whereas the luminance of the screen was less than 0.01 cd/m^2. Following the SOAs, the misspelled letters were replaced to produce the correctly spelled targets. In Experiment 2b, exposure duration of the initial presentation for all trials was 40 ms, but there were four luminance conditions: 0.75, 1.5, 3.0, and 7.0 cd/m^2. The luminance of the screen was again less than 0.01 cd/m^2. Thus, in all experiments the contrast was again close to 1.0. The room was totally dark. All visual stimuli were centered on the viewing screen.

As in Experiments 1a and 1b, each participant completed the experiment in a single session. The 798 trials were divided into two dummy blocks with 96 trials each, and three experimental blocks with 192 trials each, and the order of trials for each subject was random.

Results

As in the previous set of experiments, RTs for correct responses in the experimental conditions were averaged across participants. Within each participant, RTs outside a range of 2 *SD*s from his/her mean were trimmed. Outliers and errors accounted for about 5% of the trials. Across subjects Experiment 2a included 21,964 data points, while Experiment 2b included 20,268 data points. We will focus on the pattern of priming across experimental conditions. *F* values for main effects, as well as the means, errors, and *SD*s of each of the 24 cells are provided in Appendices D and E.

Experiment 2a

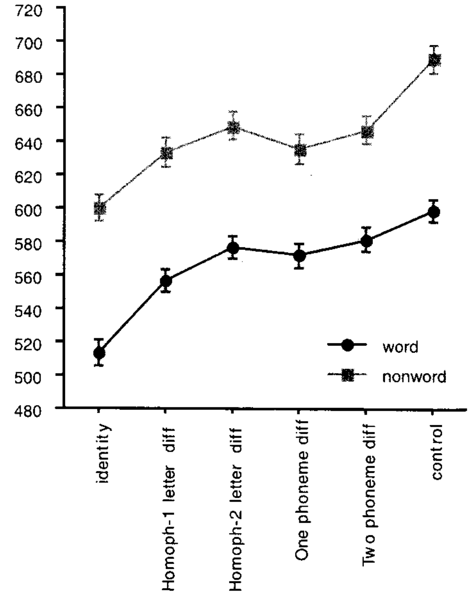

Fig. 6. Effect of the six priming conditions across all exposure durations in Experiment 2a.

Fig. 6 presents the effects of letter substitution in the six experimental conditions, averaged across all exposure durations, while Fig. 7 presents the individual effects at each SOA. The overall pattern of results mirrors the findings of Experiment 1a.

First, an identical pattern was obtained for words and nonwords, which displayed virtually parallel lines. Second, the impact of one- or two-letter alteration was again almost linear, as each letter alteration additively slowed subjects responses when phonology was kept constant. Turning to the phonological computation effects, the difference between the homophonic-one-letter different and the one-phoneme-different conditions (the *klip–CLIP*-like pseudohomophone test) was +14 ms for words, but only +1 ms for nonwords. The difference between the one-phoneme-different and the two-phoneme-different conditions was +10 msec for words and +12 ms for nonwords, while the overall summed phonological inhibition was +24 ms for words and +13 ms for nonwords. The Fisher's critical difference for significance when all data points are pooled together was about 6.8 ms ($p < .05$).

Considering the individual effects at the four SOAs, the pattern again resembles that of Experiment 1a. The very short exposure of 10 ms yielded unstable effects, where only the identity and control conditions clearly diverged from the other conditions. Both orthographic and phonological computation effects began to emerge at an SOA of 20 ms. These effects became distinct and almost linear at 30 and 40 ms SOA. The *klip–PLIP* effect at each SOA was more robust than in Experiment 1a for the words, but not for the nonwords, where it was sometimes negative. In contrast, the large phonological contrast between the homophonic-one-letter-different

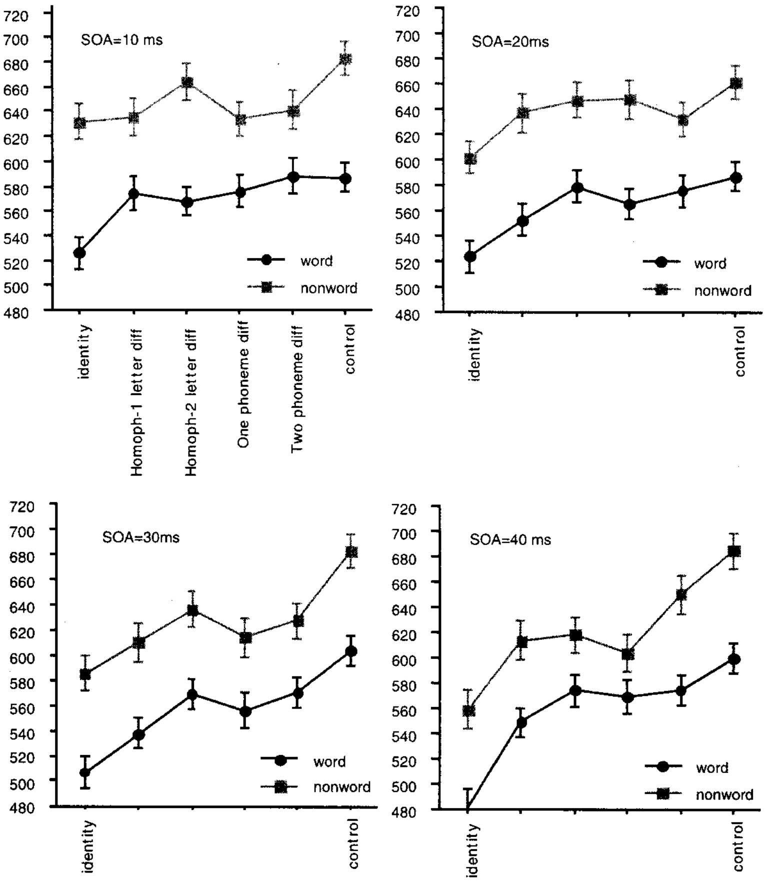

Fig. 7. Effect of the six priming conditions at 10, 20, 30, and 40 ms SOA in Experiment 2a.

and the two–three-phoneme-different condition, revealed phonological effects for words even at the shortest SOA of 10 ms. For nonwords phonological priming emerged at the longer SOAs of 30 and 40 ms.

Experiment 2b

Fig. 8 displays the effectiveness of the luminance manipulation at the chosen luminance parameters. As in the parallel Experiment 1b, latencies decreased linearly when luminance increased, and more so for words than for nonwords.

Fig. 9 presents the effects of priming in the six experimental conditions, averaged across all luminance levels, while Fig. 10 presents the individual effects at each level of luminance. The pattern of results revealed was almost identical to the parallel experiment manipulating luminance, where primes and target were two distinct cognitive events (1b).

As for the impact of letter substitutions altering the phonological structure of the initially presented targets, the phonological contrast in the *clip–KLIP*-like effect was +12 ms for words and +5 ms for nonwords. The

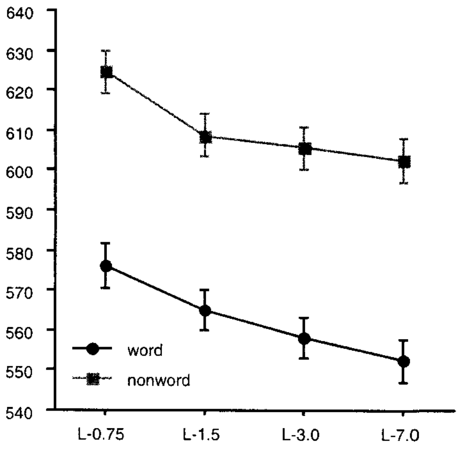

Fig. 8. Effect of luminance on lexical decision latencies in Experiment 2b.

difference between the one-phoneme- and the two–three-phoneme-different conditions was +17 ms for words and +11 ms for nonwords, so that the combined effect of the

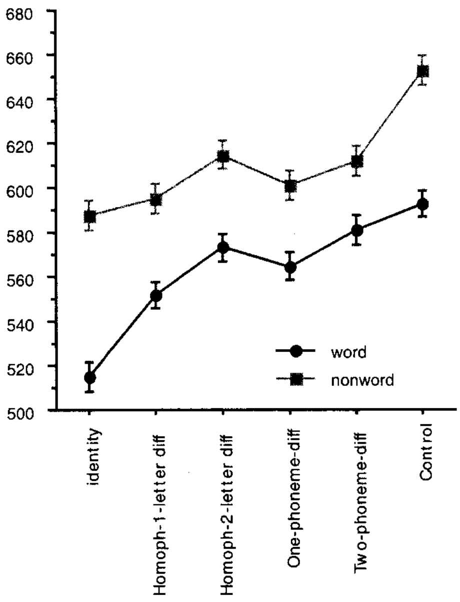

Fig. 9. Effect of the six priming conditions across all luminance levels in Experiment 2b.

phonological computation was +29 ms for words and +16 ms for nonwords. The individual effects at each level of luminance are again very similar to those in the previous experiments.

General discussion

Four independent experiments were employed to examine phonological computation in masked priming, focusing on the pseudohomophone test. The experiments used a psychophysical approach, presenting subjects with a large number of trials in which RTs to identical target words and nonwords in various priming conditions were monitored. The priming manipulation consisted of linearly increasing or decreasing orthographic similarity between the primes and the targets. In Experiment 1a, the effects of four exposure durations on phonological and orthographic priming were examined, while luminance was kept constant. In Experiment 1b exposure duration was held constant, while four levels of luminance were investigated. Exposure duration, luminance, and the same experimental conditions were also

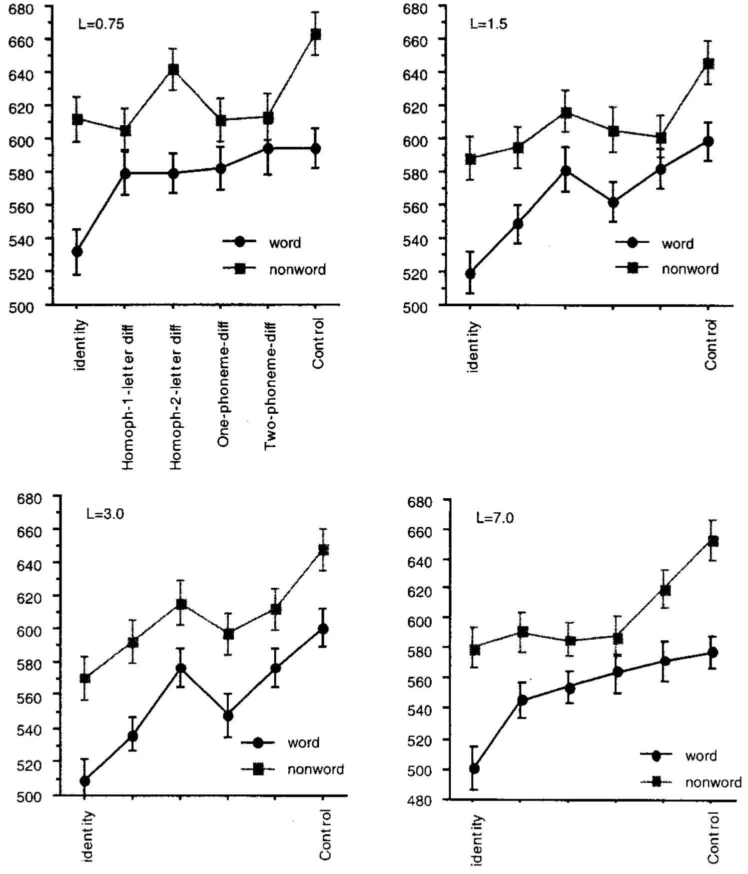

Fig. 10. Effects of the six priming conditions at 0.75, 1.5, 3.0, and 7.0 cd/m^2 in Experiment 2b.

manipulated in Experiments 2a and 2b. In these experiments, however, the stimuli were presented constantly on the screen, while some of their letters were altered on-line to convert the primes into the targets. Exposure duration and luminance are two experimental factors that control the level of energy involved in the cognitive processing of the prime. The very similar results obtained with these factors suggest that they are interchangeable in priming experiments. The two methods of presentation, one monitoring the transfer of information from prime to target, the other monitoring the cost of letter alteration, had identical predictions regarding orthographic and phonological effects. These predictions were confirmed independently, resulting in similar findings.

The results of the four experiments together provide a consistent pattern leading to straightforward conclusions. First, phonological priming effects at brief exposure durations are robust, not fragile, and can be demonstrated for words as well as nonwords. Second, the effects are not restricted to a narrow window of energy; they are revealed over a range of SOAs and luminance. Third, since the computed phonological code is initially coarse-grained, substantial phonological contrasts are required to obtain stable effects under masked presentation.

Phonological effects in masked priming

Table 2 summarizes the effects of the various phonological manipulations employed in our study, across all four experiments. This summary, which assembles close to 50,000 data points, provides a clear answer regarding the pseudohomophone test on one hand, and the *clip–KLIP* controversy, on the other. The pseudohomophone test focuses on the significant advantage that nonword-primes which are homophonic with the targets, have over orthographic controls, which do not preserve the targets' phonology. It is evident from Table 2, that when the homophonic-one-letter-different primes were compared with the two–three-phoneme-different primes (the large phonological contrast), a robust phonological effect emerged in each of the four experiments. This outcome therefore suggests that prelexical phonological computation is very fast, and occurs under masked presentation in which the primes are unavailable for report. This conclusion is compatible with the strong phonological theory (Frost, 1998). Admittedly, the table suggests that larger priming was consistently obtained for words than for nonwords. This word advantage points to some lexical contribution to the phonological priming effect. However, the robust priming obtained for *both* words and nonwords necessarily results from a prelexical component.

The demonstration of masked phonological priming effects using two different presentation techniques has implications for the DRC model (Coltheart et al., 2001). The lexical component of the priming effect reflected by the stronger phonological priming for words than for nonwords may be easily accounted for by the model. However, the overall pattern of prelexical phonological priming obtained in our study requires the model to implement very fast computations into the assembled nonlexical route to be able to simulate these effects. Since our findings demonstrate that masked phonological priming effects are apparent over a wide range of exposure durations and luminances, the speed of nonlexical phonology should be a basic property of the model. Note, however, that fast phonological computation may compromise the model's ability to account for "whammy" effects (Rastle & Coltheart, 1998), or may result in a high rate of regularization errors on exception words.

Regarding the *clip–KLIP* controversy, Table 2 suggests that this specific form of the pseudohomophone test may result in small and perhaps fragile effects. From this perspective our results stand in contrast to other studies which demonstrated phonological priming with a single phoneme difference. For example, Ferrand and Grainger (1992) have shown that KLAN primes CLAN better than SLAN (Experiments 1a, 1b and 2a, 2b). Exposure durations in these experiments, however, were relatively long, consisting of 64 ms. Since the impoverished phonological code becomes increasingly detailed with time, it is possible that this factor may account for the discrepant results.

Table 2
Phonological effects summed across experiments

	Homophonic-one-letter different vs. one-phoneme-different (clip–plip)		Homophonic-one-letter different vs. two–three-phoneme-different (large contrast)	
	Words	Nonwords	Words	Nonwords
Exp. 1a	+6	+5	+25	+19
Exp. 1b	+9	+4	+25	+19
Exp. 2a	+14	+1	+24	+13
Exp. 2b	+12	+5	+29	+16
Mean effect	+7 ms		+21 ms	

Across the various SOAs and luminance conditions, the *clip–KLIP* effect can be described as erratic at best. It was negative at some SOAs or luminance conditions, zero in others, and positive in yet others. In the present study, given the large amount of data points, statistical significance is less illuminating than measures of effect size. The overall mean of the *clip–KLIP* effect across the entire study was +7 ms. As the average standard deviation in a given cell in our study was about 70, the size of the effect was, therefore 0.1 (7/70). Such an effect size is exceedingly small (see Cohen, 1977), reflecting a correlation of only $r = .05$ between RTs and the relevant phonological manipulation. Thus, the failures of replication reported by Coltheart, Forster, and their colleagues seem to present a genuine problem with this specific form of the pseudohomophone test.

Our experiments also show that this problem is not related to luminance parameters. Experiment 1b perhaps exemplifies this best. For the ascending levels of luminance (0.75, 1.5, 3.0, 7.0 cd/m^2), the *clip–KLIP* effect was +9, +1, +6, and +13 ms, respectively, for the words, and +2, +13, +7, and −5, for the nonwords. Thus the effect seems to fluctuate in unpredictable directions at different luminance levels, showing different trends for words or nonwords, but remaining mostly small and often insignificant. The phonological contrast employed in this manipulation may just be too weak to provide a reliable and consistent facilitation. Admittedly, the energy manipulation employed in our study was limited, and not comparable to the Lukatela et al. (1998) study. Lukatela et al. compensated for the reduction in prime duration by reducing the duration of the equally luminous masks and targets, to protect against energy-based masking (see also Lukatela, Eaton, Lee, & Turvey, 2001; Lukatela & Turvey, 2000a, 2000b, for similar adjustments of the duration and design of the forward mask). In contrast, our study did not manipulate durations or designs of masks and targets. Since our forward mask was prolonged, and the target remained on the screen until subjects' response, the prime's energy was relatively low given its brief presentation at all exposure parameters.

But note, however, that the low energy of our primes did not interfere with the robust phonological effects obtained in the two other phonological contrasts (the homophonic-one-letter-different vs. the one-phoneme-different, and vs. the two–three-phoneme-different). This finding suggests that the weakness of the *clip–KLIP* contrast is probably related to the window of phonology, not that of energy. Thus, as in the results for backward masking (Gronau & Frost, 1997), small phonological contrasts that are due to one-consonant alterations have a lower probability of demonstrating masked phonological priming. However, keeping the orthographic change constant, if the substituted letter alters the phonological structure of the target more dramatically, the homophonic prime will gain substantial benefit over the orthographic control prime.

The outcome of the *clip–KLIP* test, in conjunction with the results of the large phonological contrasts in our study, provide support for an important theoretical claim of the strong phonological theory (Frost, 1998), namely, that the computed phonological code is initially impoverished and coarse-grained. Small phonological differences between primes and targets may not be detected due to the impoverishment of the computed phonological representation. Hebrew provides an opportunity to test a wider range of consonantal alterations than English, as it is not restricted to C/K substitutions. Nevertheless, the *clip–PLIP* phonological contrast did not always yield a sizeable effect. By contrast, our data clearly suggest that larger phonological differences can be easily detected, resulting in substantial effects of masked phonological priming.

The theoretical assumption that the phonological code is initially impoverished eventually requires a more specific description of which features are computed initially, and which subsequently. Admittedly, little unequivocal evidence is currently available to provide a detailed description of this dynamic process. For example, Berent and Perfetti (1995) suggested that all consonants are initially computed at a first cycle of about 14–30 ms from stimulus onset, whereas vowels are computed at a second cycle up to 40–50 ms. This finding could provide an initial taxonomy for the gradual specification of the phonological code. It does not, however, coincide with our results suggesting that readers may not detect differences of a single consonant. But note that recently Lukatela and Turvey (2000a) evaluated the two-cycle model of Berent and Perfetti in an extensive series of forward masking experiments. Their findings suggest that at the first cycle of computation vowel-preserving primes are as effective as consonant-preserving primes. Similarly, Colombo (2000) showed that in the shallow Italian, there is no temporal advantage of consonant computation over vowel computation.

All of these reported findings demonstrate the complexity of defining the exact aspects of phonology which are specified in the initial computed representation, and those which remain underspecified. These specific phonological features may depend on the depth of the orthography in general (Frost et al., 1987), or on the characteristics of a specific set of stimuli in particular. Thus, it is possible that small or large phonological contrasts are characterized not simply by the number of altered consonants (one vs. two), but by a more refined description of phonetic features. For example, the phonological contrast between any pair of consonants is determined by three independent dimensions: place of articulation, manner of articulation, and voicing. Thus, any two consonants may differ from each other in either one, two or three dimensions, with increasing phonological similarity or dissimilarity between them. Since these were not controlled in any of the studies we described so far, they may account for some the discrepancies in the reported findings. Nevertheless, describing the precise nature of coarse-grained representations remains an empirical issue that may be resolved through experimentation.

It is at this point in our discussion that we should acknowledge that theoretical frameworks other than the strong phonological view are also compatible with our findings. The strong phonological view regards the increasing effects of orthographic and phonological dissimilarity as independent. However, if our view of lexical architecture involves lexical representations which are amodal in the sense they are orthographic and phonological at the same time ("phonographic" representations), then the similarity between primes and targets would be reflected by the joint or additive similarities of orthographic and phonological forms. Thus, any increasing similarity or dissimilarity between primes and targets, whether orthographic or phonological, affects the size of the priming in some combinatorial fashion. The phonological coherence theory (e.g., van Orden & Goldinger, 1994) has a somewhat similar approach, as it regards lexical activation as a resonance process, in which orthographic, phonological, and semantic sublexical units interact with one another. Greater coherence is always achieved when fewer letters and fewer phonemes are altered. It is not simple to distinguish empirically between these approaches and the strong phonological view. In fact, the strong phonological view argues at length why a theory of lexical representation should not postulate amodal representations (*the nonneutrality of the core lexical representation*, p. 75). However, the theory clearly acknowledges that this is an axiomatic assumption, not an empirical claim.

Masked priming for words and nonwords

One important finding is the similar pattern of priming found for words and nonwords. This outcome stands in sharp contrast to many studies that employed masked priming, all showing that form priming effects occur reliably for words but not for nonwords (Forster, 1987; Forster & Davis, 1984; Frost, Forster, & Deutsch, 1997). The account provided for this pattern of results was that the priming effect in masked presentations depends on the existence of a lexical representation. This is because the facilitation in masked priming was traditionally considered as deriving from a faster *recognition* of the word target, given its shared properties with the prime. Since nonwords are not lexically represented and recognized, they cannot benefit from the prime. How can we reconcile these findings with ours?

The commonly accepted explanation for the priming effects under masked presentation is outlined by the entry-opening model (Forster & Davis, 1984). The model suggests that if the prime is a close match to the target, due to their shared structural properties, then the prime may open the lexical entry for the target. This will necessarily result in a shorter processing of the target, thereby producing the priming effect. What could make the prime a close match to the target is either orthographic or phonological overlap (see Forster & Azuma, 2000, for a discussion). Thus, the entry-opening model focuses on the savings due to locating the target in the lexicon.

We propose, however, that priming effects in masked presentation probably have two components: a prelexical computation component and a lexical location one. The prelexical computation component involves the process of registering the orthographic and phonological properties, which form the basis for lexical search or activation, making the prime a close match to the target. This constituent of the priming effect, being prelexical, is similar for words and nonwords. The lexical location component involves actually locating the target in the lexicon. For this constituent of the priming effect, which is the main focus of the entry-opening model, words and nonwords obviously diverge. Within a single presentation of a stimulus, most studies show that the reliable and significant part of the priming effect involves the lexical component. The prelexical computational component is reflected in a small and unreliable facilitation of about 6–8 ms across studies (see Forster, 1998, for a discussion).

Our psychophysical paradigm, however, involved *repeated* presentation of words and nonwords. This manipulation necessarily reduced the location component, as the targets were repeatedly found, recognized or activated. Thus one possible interpretation for the similar pattern of results obtained for words and nonwords is that the repetition paradigm enhanced the relative share of the computation component at the expense of the location component. Since the prelexical computational processes are similar for words and nonwords, they both reveal priming effects. Given the theoretical focus of the present paper, the repetition procedure thus has an additional benefit; it centers on the *computations* involved in processing the primes and the targets.

One possible criticism of this interpretation is that if the location component is eliminated, the overall priming effect is expected to be reduced by a similar factor. The facilitation obtained in the identity condition in our experiments does not seem reduced; rather it matches the usual identity priming effects in masked priming in Hebrew with single target-presentations (e.g., Frost et al., 1997). However, it is possible that once the relative share of the computation component is enhanced by repeated exposures, the overall priming it produces may be extended due to the increased efficiency of the computation process.

An alternative account for the word-nonword priming similarity focuses on episodic records that are characteristic of repeated presentations. In this view, the repeated exposure of words and nonwords results in their representations being stored in episodic memory storage. The computation process and the resulting decision regarding the lexicality of both words and nonwords follows a search process that is conducted within this episodic memory storage. Since both the word and the nonword targets were stored in the episodic storage, similar priming patterns are expected for both. Note that this account could explain our observed phenomenon of hyper-priming. The decision regarding an item that has been processed before may affect the response stage as well, and thus amplify the priming effect beyond the SOA time limit.

To accurately determine which of the two alternative explanations accounts better for our results, further research mapping the development of priming effect in each single presentation of each word and nonword is required. This is beyond the scope of the present paper, as our data did not track these sequential changes. Note, however, that both interpretations of the word-nonword priming similarity are orthogonal to our main conclusions regarding the robustness of phonological effects. Whether the repeated presentations reduced the location component, or whether they resulted in episodic memory storage including both words and nonwords, is independent of the main finding of our experiments. In both accounts it is evident that the phonological properties of the printed stimuli were computed fast enough to provide robust phonological priming effects for words as well as nonwords, that these effects were not energy dependent, and that they were determined by the phonological contrast between primes and targets. It is possible that the speed of both orthographic and phonological processing was somewhat enhanced in our study as a result of the repeated presentations, but our study confirms that the cognitive operations involved in computing a phonological code can be demonstrated at very early onsets.

A psychophysical approach to visual word recognition: Methodological considerations

Admittedly, true psychophysical methods involve the practicing of subjects for days or even weeks. In that sense our use of the term "psychophysical" is more metaphorical than practical. Nevertheless, four salient features which are characteristic of psychophysical research were employed in our experimental approach. First, we employed a parametric design involving a gradual increase in phonological and orthographic similarity in the various experimental conditions. Second, we monitored the effect of gradual changes of exposure parameters, such as SOA and luminance. Third, we used of a full within-subject within-stimulus design, so that subject and item variability would not interact with the different experimental conditions. Finally, we collected a large number of repeated measures within subjects, to increase our confidence in the reliability of our findings.

The clear benefits of using psychophysical methods in visual word recognition research has been shown in several investigations by Grainger, Jacobs, and their colleagues (e.g., Grainger & Jacobs, 1991; Jacobs, Grainger, & Ferrand, 1995). For example, the aim of their incremental priming technique was to determine within-condition priming effects by comparing the effects obtained in a any given experimental condition to a baseline in presentation involves minimal intensity. Although our psychophysical approach had other additional goals, some similarity to the technique developed by Grainger and Jacobs is apparent if the pattern of priming we obtained in the very brief exposure durations or luminance parameters is compared to the priming we obtained with enhanced luminance and longer exposures of the primes. Very small and unstable effects were revealed in the brief exposure duration or luminance parameters, whereas larger and more stable effects emerged with greater stimulus intensity. However, independently of the priming baseline issue, which was the focus of the incremental priming technique, we suggest that, in general, a psychophysical approach which assembles a mass of data points through repeated measures may be an interesting avenue for resolving inconsistencies among studies in visual word recognition. This is especially true for experimental designs which focus on binary decisions, where inconsistent conclusions across studies may simply reflect differences in power, given differences in sample size and error variance.

However, our choice of a parametric design which gradually increases phonological and orthographic similarity in the various experimental conditions is not merely methodological, but stems from a theoretical stand regarding the nature of phonological and orthographic computation. The strong phonological view has consistently argued that experimenters investigating phonological encoding should not seek binary decisions (e.g., is there phonological priming or not?), but should focus on mapping the dynamic properties of phonological computation. Thus, the claim is that we should not to fix our experimental camera at the finish line of the cognitive events, but try to film their on-line, step-by-step development (Frost, 1998, p. 95). Our psychophysical approach provides an appropriate method for carrying out such research. Perhaps the most important conclusion that emerges from our results is that phonological (as well as orthographic) effects in masked priming are not all-or-none. Rather, they present a continuum, in which greater similarity or dissimilarity between primes and targets results in larger facilitation or inhibition effects. Such findings can be revealed only if the experimental design is not restricted to simple binary decisions as to whether or not to reject the null hypothesis.

The psychophysical design we employed is not without potential pitfalls. Unlike single visual presentation, the repetition of verbal stimuli may create experiment-specific effects, which should be taken into consideration when interpreting the data. This is, after all, a traditional question in experimental psychology: Could it be that the specific demand characteristics of our design have themselves induced our results? The similarity of the priming pattern obtained in our study for words and nonwords could be an example of such experiment-specific effects. However, without resorting to the obvious argument that almost every experimental technique in visual word recognition deviates from "normal" word recognition, the consistent advantage of strong over weak phonological contrasts in four independent experiments employing an array of exposure techniques cannot be easily be traced to the simple effect of repetition.

In conclusion, the present study provides strong evidence that fast nonlexical phonological computation occurs under masked presentation over a wide range of exposure parameters. However, since the phonological code is initially coarse-grained, the richness of the phonological manipulation is the crucial factor in determining the size of the phonological effect.

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Appendix A

The Hebrew Alphabet

Hebrew print	Orthographic transcription	Phonetic transcription
א	ς	ς
ב	B	b,v
ג	G	g
ד	D	d
ה	H	h
ו	W	o,u,v
ז	Z	z
ח	X	x
ט	τ	t
י	I	I, y
ך / כ	k, K	k, x
ל	L	l
ם / מ	m, M	m
ן / נ	n, N	n
ס	S	s
ע	?	ς
ף/פ	p, P	p,f
ץ / צ	*c*, *C*	c
ק	Q	k
ר	R	r
ש	S	s, sh
ת	T	t

The Hebrew letters א (ς) and ע (?) stand for glottal and pharyngeal stops, respectively. The letters k, m, n, p, and *c* have different forms when they appear at the end of the word.

Appendix B

Reaction times, percent errors and (*SD*s) of the 24 experimental cells in Experiment 1a.

Condition	Identity	Homophonic-one-letter-different	Homophonic-two-letters-different	One phoneme different	Two phoneme different	Control
Words						
SOA = 10	506	544	543	532	560	561
	2.8% (69)	11.8% (67)	2.4% (66)	5.1% (71)	10% (73)	4.7% (69)
SOA = 20	505	523	542	525	544	554
	3.2% (82)	4.1% (67)	5.8% (67)	8.% (65)	5.6% (71)	4.7% (56)
SOA = 30	490	517	540	533	545	566
	2.8% (68)	1.5% (76)	4.5% (66)	12.2% (74)	8.0% (68)	5.1% (67)
SOA = 40	473	516	547	539	554	564
	3.2% (89)	(62)	4.3% (66)	10.9% (71)	8.3% (67)	3.4% (69)
Nonwords						
SOA = 10	589	586	597	587	588	616
	8.8% (71)	12.2% (71)	9.4% (66)	4.9% (67)	14.1% (72)	9% (67)
SOA = 20	575	580	594	589	590	605
	6.2% (72)	6.4% (67)	6% (73)	0.6% (74)	4.3% (73)	6% (71)
SOA = 30	550	559	587	569	587	617
	4.3% (69)	4.3% (72)	7.7% (70)	12.6% (64)	4.0% (81)	7.9% (75)
SOA = 40	530	573	573	568	604	637
	8.5% (77)	3.4% (76)	4.95% (76)	5.8% (78)	12% (69)	11.1% (62)

Source	*df*	Sum of square	Mean square	*F*-value	*P*-value
Condition	5	64593.5	138918.7	133.2	0.0001
Error	190	198205.2	1043.2		
SOA	3	41267.0	13755.7	11.0	0.0001
Error	114	41997.0	1245.6		
Wordness	1	1311520.6	1311520.6	125.4	0.0001
Error	38	397297.2	10455.2		
Cond. * SOA	15	126037.6	8402.5	11.4	0.0001
Error	570	419761.3	736.4		
Cond * Word.	5	37801.7	7560.3	8.8	0.0001
Error	190	163410.3	860.1		
Word * SOA	3	6864.0	2288.2	2.5	0.0663
Error	114	106051.1	930.3		
Cond * SOA * word	15	39300.4	2620.0	3.4	0.0001
Error	570	434085.3	761.6		

Appendix C

Reaction times, percent errors and (*SD*s) of the 24 experimental cells in Experiment 1b.

Condition	Identity	Homophonic-one-letter-different	Homophonic-two-letter-different	One phoneme different	Two phoneme different	Control
Words						
LUM = 0.75	533	543	569	552	572	576
	1% (64)	2.3% (64)	2.7% (58)	4.6% (50)	9.8% (52)	5.2% (56)
LUM = 1.5	508	538	559	539	565	582
	2.7% (55)	3.1% (52)	4.6% (55)	2.0% (57)	5.2% (47)	4.6% (50)
LUM = 3.0	505	534	548	534	552	582
	3.5% (63)	4% (51)	5.2% (60)	2.5% (58)	3.0% (54)	4.4% (54)
LUM = 7.0	484	526	539	550	555	558
	4.8% (63)	1.0%. (58)	2.7% (43)	5.4% (64)	5.2% (54)	3.3% (55)
Nonwords						
LUM = 0.75	597	592	620	594	612	641
	9.6% (60)	12.3% (62)	6.5% (60)	6.5% (64)	12.3% (54)	7.9% (59)

Appendix C (*continued*)

Condition	Identity	Homophonic-one-letter-different	Homophonic-two-letter-different	One phoneme different	Two phoneme different	Control
LUM = 1.5	576	586	597	599	597	627
	5.6% (50)	5% (60)	8.1% (60)	3.1% (62)	6% (59)	5.4% (56)
LUM = 3.0	566	578	597	585	600	640
	7.1% (61)	4.8% (59)	9% (64)	10% (64)	1.5% (59)	7.3% (60)
LUM = 7.0	571	583	581	578	607	632
	7.1% (55)	3.8% (61)	4.6% (61)	6.3% (69)	10.2% (65)	7.7% (67)

Source	*df*	Sum of square	Mean square	*F*-value	*P*-value
Condition	5	698523.5	139704.7	141.22	0.0001
Error	195	192905.6	989.3		
Luminance	3	101715.5	33905.2	45.5	0.0001
Error	117	87211.0	745.0		
Wordness	1	1375322.7	1375322.7	136.3	0.0001
Error	39	393632.6	10093.1		
Cond. * Lum.	15	49360.2	3290.7	3.6	0.0001
Error	585	528154.7	902.8		
Cond * word.	5	39556.2	7911.2	8.2	0.0001
Error	195	188455.5	966.4		
Word * Lum	3	4468.1	1489.7	1.6	0.1894
Error	117	107832.8	921.7		
Cond * Lum * Word	15	30487.2	2032.5	2.3	0.0030
Error	585	508965.8	870.0		

Appendix D

Reaction times, percent errors and (*SD*s) of the 24 experimental cells in Experiment 2a.

Condition	Identity	Homophonic-one-letter-different	Homophonic-two-letter-different	One phoneme different	Two phoneme different	Control
Words						
SOA = 10	526	574	567	576	588	587
	2.1% (84)	2.5% (75)	4% (65)	6.3% (81)	10.3% (77)	2.3% (73)
SOA = 20	524	553	579	565	576	587
	1% (81)	2.9% (82)	3.1% (74)	(79)	4.6% (76)	1.5% (76)
SOA = 30	506	538	570	556	571	604
	2.9% (87)	4.1% (81)	3.5% (65)	10.3% (82)	(74)	2.9% (77)
SOA = 40	482	549	574	569	575	600
	4% (88)	3.0% (76)	4% (75)	9% (78)	6.9% (77)	2.7% (82)
Nonwords						
SOA = 10	632	635	664	634	641	683
	7.3% (96)	11.3% (96)	4.4% (103)	4.8% (95)	13.3% (105)	5.4% (97)
SOA = 20	602	637	647	647	632	661
	5.4% (88)	4% (121)	5.9% (99)	0.4% (101)	3.5% (87)	4.2% (95)
SOA = 30	586	610	636	614	628	683
	3.1% (99)	2.9% (105)	8.8% (93)	11.9% (92)	9.0%(107)	4.8% (88)
SOA = 40	559	614	618	604	650	685
	4.6% (109)	1.5% (102)	3.5% (95)	6.5% (93)	6.9% (96)	8.3% (90)

Source	*df*	Sum of square	Mean square	*F*-value	*P*-value
Condition	5	1227417.8	245483.6	175.8	0.0001
Error	195	272274.0	1396.3		
SOA	3	108087.1	36029.0	25.84	0.0001
Error	117	163153.1	1394.5		

Appendix D (*continued*)

Source	*df*	Sum of square	Mean square	*F*-value	*P*-value
Wordness	1	2390501.2	2390501.2	108.9	0.0001
Error	39	855942.9	21947.3		
Cond * SOA.	15	163227.8	10881.9	8.0	0.0001
Error	585	799732.2	1367.1		
Cond * Word.	5	41390.5	8278.1	6.5	0.0001
Error	195	246666.7	1265.0		
Word * SOA	3	15545.8	5181.9	4.2	0.0073
Error	117	144250.3	1232.9		
Cond* SOA* Word	15	58482.9	3898.9	3.3	0.0001
Error	585	699291.0	1195.4		

Appendix E

Reaction times, percent errors and (*SD*s) of the 24 experimental cells in Experiment 2b.

Condition	Identity	Homophonic-one-letter-different	Homophonic-two-letter-different	One phoneme different	Two phoneme different	Control
Words						
LUM = 0.75	532	579	579	582	594	594
	3.2% (86)	14.6% (78)	3.6% (71)	6.1% (81)	7.1% (93)	4.3% (80)
LUM = 1.5	519	549	581	562	582	599
	3.4% (88)	3.6% (69)	6.3% (81)	5. 0% (78)	6.5% (73)	3.8% (73)
LUM = 3.0	509	536	576	548	577	600
	2.9% (84)	3.8% (65)	3.6% (69)	4.2% (79)	5.0% (71)	4.5% (71)
LUM = 7.0	500	546	555	564	572	577
	4.3% (90)	(85)	4.1% (58)	6.1% (80)	6.8% (92)	2.7% (63)
Nonwords						
LUM = 0.75	612	605	642	611	613	663
	7.2% (82)	11% (83)	5.6% (77)	2% (86)	13.5% (75)	5.4% (87)
LUM = 1.5	588	595	616	605	601	646
	5% (79)	3.8% (71)	3.6% (82)	6.6% (88)	2.5% (80)	3.8% (81)
LUM = 3.0	570	592	615	597	612	648
	2.9% (81)	3.2% (88)	8.6% (81)	11.3% (66)	5.2%(82)	2.9% (80)
LUM = 7.0	580	591	586	588	620	653
	5% (78)	(86)	2% (74)	4.5% (81)	7.9% (77)	7.4% (87)

Source	*df*	Sum of square	Mean square	*F*-value	*P*-value
Condition	5	839538.7	167907.7	133.3	0.0001
Error	180	226710.2	1259.5		
Luminance	3	121798.4	40599.5	41.4	0.0001
Error	108	105938.2	980.9		
Wordness	1	1006305.5	1006305.5	143.2	0.0001
Error	36	252930.2	7025.8		
Cond. * Lum	15	56516.0	3767.7	3.5	0.0001
Error	540	579027.6	1072.3		
Cond * Word	5	83250.0	16650.0	14.5	0.0001
Error	180	207252.8	1151.4		
Word * Lum	3	2503.0	834.3	0.7	0.5512
Error	108	127840.7	1183.7		
Cond * Lum * Word	15	49750.5	3316.7	3.67	0.0001
Error	540	487459.8	902.7		

Appendix F

List of words and nonwords employed in the experiments.
Words

	Identity (Target)	Homophonic One letter different	Homophonic Two letter different	One phoneme different	Two phoneme different	Control
1. Prime	כפית	קפית	קפיט	כפיז	כפזת	זבלד
Printed Form	KPIT	QPIT	QPI*t*	KPIZ	KPZT	ZBLD
Phonologic Form	/kapit/	/kapit/	/kapit/	/kapiz/	/kapezet/	/zablad/
2. Prime	אוכל	אוחל	עוחל	אוכב	אבכל	תרטס
Printed Form	çWKL	çWXL	?WXL	çWKB	çBKL	TR*t*s
Phonologic Form	/çoxel/	/çoxel/	/çoxel/	/çoxev/	/çavxal/	/tartas/
3. Prime	כפתור	כפטור	קפטור	כפתיר	כפתבר	המשיז
Printed Form	KPTWR	KP*t*WR	QP*t*WR	KPTIR	KPTBR	HMSIZ
Phonologic Form	/kaftor/	/kaftor/	/kaftor/	/kaftir/	/kaftavar/	/himshiz/
4. Prime	כיתה	כיטה	קיטה	כותה	כחתה	בסוז
Printed Form	KITH	KI*t*H	QI*t*H	KWTH	KXTH	BsWZ
Phonologic Form	/kita/	/kita/	/kita/	/kota/	/kaxta/	/basoz/
5. Prime	מכונית	מכוניט	מחוניט	מכוניג	מכונגת	בכמלגי
Printed Form	MKWNIT	MKWNI*t*	MXWNI*t*	MKWNIG	MKWNGT	BKMLGI
Phonologic Form	/mexonit/	/mexonit/	/mexonit/	/mexonig/	/mexoneget/	/baxmalgi/
6. Prime	קטיף	קתיף	כתיף	קטיד	קטלף	אמנל
Printed Form	Q*t*Ip	QTIp	KTIp	Q*t*ID	Q*t*Lp	çMNL
Phonologic Form	/katif/	/katif/	/katif/	/katid/	/katlaf/	/çamnal/
7. Prime	כתיבה	כטיבה	קטיבה	כסיבה	כתסבה	ענדור
Printed Form	KTIBH	K*t*IBH	Q*t*IBH	KsIBH	KTsBH	?NDWR
Phonologic Form	/ktiva/	/ktiva/	/ktiva/	/ksiva/	/katsava/	/çandor/
8. Prime	עותק	עוטק	אוטק	עיתק	עפתק	חדפי
Printed Form	?WTQ	?W*t*Q	çW*t*Q	?ITQ	?PTQ	XDPI
Phonologic Form	/çotek/	/çotek/	/çotek/	/çitek/	/çaftek/	/xadafi/
9. Prime	קשת	קשט	כשט	קרת	קית	רבד
Printed Form	QST	QS*t*	KS*t*	QRT	QIT	RBD
Phonologic Form	/keshet/	/keshet/	/keshet/	/keret/	/kit/	/ravad/
10. Prime	אחות	אחוט	עחוט	אחית	אחנת	גיזס
Printed Form	çXWT	çXW*t*	?XW*t*	çXIT	çXNT	GIZS
Phonologic Form	/çaxot/	/çaxot/	/çaxot/	/çaxit/	/çaxenet/	/gizes/
11. Prime	כרית	כריט	קריט	כריל	נרדת	סאלו
Printed Form	KRIT	KRI*t*	QRI*t*	KRIL	NRDT	sçLW
Phonologic Form	/karit/	/karit/	/karit/	/karil/	/naredet/	/salo/
12. Prime	עכביש	עקביש	אקביש	עכביל	עכבלש	גמוסת
Printed Form	?KBIS	?QBIS	çQBIS	?KBIL	?KBLS	GMWsT
Phonologic Form	/çakavish/	/çakavish/	/çakavish/	/çakavil/	/çakvalash/	/gamoset/
13. Prime	ארטיק	ארתיק	ערתיק	ארטוק	ארטסק	דשמלר
Printed Form	çR*t*IQ	çRTIQ	?RTIQ	çR*t*WQ	çR*t*sQ	DSMLR
Phonologic Form	/çartik/	/çartik/	/çartik/	/çartuk/	/çartesek/	/dashmlar/

Appendix F (*continued*)

		Identity (Target)	Homophonic One letter different	Homophonic Two letter different	One phoneme different	Two phoneme different	Control
14.	Prime	קשית	קשיט	כשיט	קשיל	קשלת	גלרו
	Printed Form	QSIT	QSI*t*	KSI*t*	QSIL	QSLT	GLRW
	Phonologic Form	/kashit/	/kashit/	/kashit/	/kashil/	/kashelet/	/galru/
15.	Prime	כנסת	כנסט	קנסט	כנסל	כוסת	בשפא
	Printed Form	KNsT	KNs*t*	QNs*t*	KNsL	KWsT	BSPς
	Phonologic Form	/kneset/	/kneset/	/kneset/	/knesel/	/koset/	/bashfa/
16.	Prime	עתיד	עטיד	אטיד	עתוד	עתגד	פגנו
	Printed Form	?TID	?*t*ID	ς*t*ID	?TWD	?TGD	PGNW
	Phonologic Form	/çatid/	/çatid/	/çatid/	/çatud/	/çatgad/	/pagnu/
17.	Prime	כרטיס	כרתיס	קרתיס	כרטיל	כרטלס	דמלוע
	Printed Form	KR*t*Is	KRTIs	QRTIs	KR*t*IL	KR*t*Ls	DMLW?
	Phonologic Form	/kartis/	/kartis/	/kartis/	/kartil/	/kartlas/	/damloça/
18.	Prime	תקרית	תקריט	טקריט	תקריד	תקרדת	אשדבז
	Printed Form	TQRIT	TQRI*t*	*t*QRI*t*	TQRID	TQRDT	çSDBZ
	Phonologic Form	/takrit/	/takrit/	/takrit/	/takrid/	/takredet/	/çashdavaz/
19.	Prime	תאטרון	תאתרון	תעתרון	תאטרין	תאטרלן	רלזידה
	Printed Form	TçtRWn	TçTRWn	T?TRWn	Tç*t*RIn	TçtRLn	RLZIDH
	Phonologic Form	/teçatron/	/teçatron/	/teçatron/	/teçatrin/	/teçatralan/	/relzida/
20.	Prime	חביתה	חביתא	חביטא	חבותה	חבנתה	מגאסף
	Printed Form	XBITH	XBITç	XBI*t*ç	XBWTH	XBNTH	MGçsp
	Phonologic Form	/xavita/	/xavita/	/xavita/	/xavuta/	/xavnata/	/magasaf/
21.	Prime	קדח	קדך	כדך	קבח	קוח	רזט
	Printed Form	QDX	QDk	KDk	QBX	QWX	RZ*t*
	Phonologic Form	/kadax/	/kadax/	/kadax/	/kabax/	/koax/	/razat/
22.	Prime	כחול	ככול	קכול	כחיל	כחסל	נימץ
	Printed Form	KXWL	KKWL	QKWL	KXIL	KXsL	NIMc
	Phonologic Form	/kaxol/	/kaxol/	/kaxol/	/kaxil/	/kaxsal/	/nimec/
23.	Prime	עמית	עמיט	אמיט	עמיג	עמגת	פגוח
	Printed Form	?MIT	?MI*t*	çMI*t*	?MIG	?MGT	PGWX
	Phonologic Form	/çamit/	/çamit/	/çamit/	/çamig/	/çameget/	/pagoax/
24.	Prime	תפריט	תפרית	טפרית	תפרין	תפרנט	מצושח
	Printed Form	TPRI*t*	TPRIT	*t*PRIT	TPRIn	TPRN*t*	MCWSX
	Phonologic Form	/tafrit/	/tafrit/	/tafrit/	/tafrin/	/tafranet/	/mecushax/
25.	Prime	אכזבה	אחזבה	עחזבה	אכמבה	אכזיה	בליגר
	Printed Form	çKZBH	çXZBH	?XZBH	çKMBH	çKZIH	BLIGR
	Phonologic Form	/çaxzava/	/çaxzava/	/çaxzava/	/çaxmava/	/çaxziya/	/bliger/
26.	Prime	תכסיס	תחסיס	טחסיס	תכסוס	תכסלר	אלפוש
	Printed Form	TKsIs	TXsIs	*t*XsIs	TKsWs	TKsLR	çLPWS
	Phonologic Form	/taxsis/	/taxsis/	/taxsis/	/taxsus/	/taxslar/	/çalpush/

Appendix F (*continued*)

	Identity (Target)	**Homophonic One letter different**	**Homophonic Two letter different**	**One phoneme different**	**Two phoneme different**	**Control**
27. Prime	כוכב	כוחב	קוחב	כוכף	כפכב	משזס
Printed Form	KWKB	KWXB	QWXB	KWKp	KPKB	MSZs
Phonologic Form	/koxav/	/koxav/	/koxav/	/koxaf/	/kafkav/	/mishzas/
28. Prime	תאריך	תעריך	טעריך	תאריש	תארשך	גומסה
Printed Form	TçRIk	T?RIk	*T*?RIk	TçRIS	TçRSk	GWMsH
Phonologic Form	/taçarix/	/taçarix/	/taçarix/	/taçarish/	/taçarshax/	/gumsa/
29. Prime	תפנית	תפניט	טפניט	תפנות	תפנגת	רגנפו
Printed Form	TPNIT	TPNI*t*	*t*PNI*t*	TPNWT	TPNGT	RGNPW
Phonologic Form	/tafnit/	/tafnit/	/tafnit/	/tafnut/	/tafneget/	/ragnafu/
30. Prime	תותח	תותך	טותך	תיתח	תזתח	אידר
Printed Form	TWTX	TWTk	*t*WTk	TITX	TZTX	çIDR
Phonologic Form	/totax/	/totax/	/totax/	/titax/	/taztax/	/çider/
31. Prime	קטין	קתין	כתין	קטים	קטמן	זפצב
Printed Form	Q*t*In	QTIn	KTIn	Q*t*Im	Q*t*Mn	ZPCB
Phonologic Form	/katin/	/katin/	/katin/	/katim/	/katman/	/zafcav/
32. Prime	תפקיד	תפכיד	טפכיד	תפקיב	תפקבד	אצרוז
Printed Form	TPQID	TPKID	*t*PKID	TPQIB	TPQBD	çCRWZ
Phonologic Form	/tafkid/	/tafkid/	/tafkid/	/tafkib/	/tefkbad/	/çecroz/
33. Prime	קדחת	קדחט	כדחט	קדחש	קדית	רוסע
Printed Form	QDXT	QDX*t*	KDX*t*	QDXS	QDIT	RWs?
Phonologic Form	/kadaxat/	/kadaxat/	/kadaxat/	/kadaxash/	/kadit/	/roseça/
34. Prime	כיכר	כיקר	קיקר	כוכר	כבכר	טלוד
Printed Form	KIKR	KIQR	QIQR	KWKR	KBKR	*t*LWD
Phonologic Form	/kikar/	/kikar/	/kikar/	/kukar/	/kavkar/	/talud/
35. Prime	דכאון	דכעון	דקעון	דכאול	דכאמל	הלדות
Printed Form	DKçWn	DK?Wn	DQ?Wn	DKçWL	DKçML	HLDWT
Phonologic Form	/dikaçon/	/dikaçon/	/dikaçon/	/dikaçol/	/dikçamal/	/haldut/
36. Prime	עתיק	עטיק	אטיק	עתוק	עתמק	חפנר
Printed Form	?TIQ	?*t*IQ	ç*t*IQ	?TWQ	?TMQ	XPNR
Phonologic Form	/çatik/	/çatik/	/çatik/	/çatuk/	/çatmak/	/xafnar/
37. Prime	משאית	משאיט	מסאיט	משאיג	משאגת	צבגלס
Printed Form	MSçIT	MSçI*t*	MsçI*t*	MSçIG	MSçGT	CBGLs
Phonologic Form	/masaçit/	/masaçit/	/masaçit/	/masaçig/	/masçeget/	/cavglas/
38. Prime	מטבח	מטבך	מתבך	מטבש	מיבח	נידר
Printed Form	M*t*BX	M*t*Bk	MTBk	M*t*BS	MIBX	NIDR
Phonologic Form	/mitbax/	/mitbax/	/mitbax/	/mitbash/	/mibax/	/nider/
39. Prime	שוקת	שוקט	שוכט	שיקת	שמקת	עזרב
Printed Form	SWQT	SWQ*t*	SWK*t*	SIQT	SMQT	?ZRB
Phonologic Form	/shoket/	/shoket/	/shoket/	/shiket/	/shameket/	/çazrab/

Appendix F (*continued*)

		Identity (Target)	Homophonic One letter different	Homophonic Two letter different	One phoneme different	Two phoneme different	Control
40.	Prime	עתירה	עטירה	אטירה	עתילה	עתנרה	פובשז
	Printed Form	?TIRH	?*t*IRH	ç*t*IRH	?TILH	?TNRH	PWBSZ
	Phonologic Form	/çatira/	/çatira/	/çatira/	/çatila/	/çatnara/	/pobshaz/
41.	Prime	כיפה	כיפא	קיפא	כיגה	כנפה	נלצד
	Printed Form	KIPH	KIPç	QIPç	KIGH	KNPH	NLCD
	Phonologic Form	/kipa/	/kipa/	/kipa/	/kiga/	/knafa/	/nilcad/
42.	Prime	תחביר	תכביר	טכביר	תחבין	תחבנר	הלגמש
	Printed Form	TXBIR	TKBIR	*t*KBIR	TXBIn	TXBNR	HLGMS
	Phonologic Form	/taxbir/	/taxbir/	/taxbir/	/taxbin/	/taxbner/	/halgmash/
43.	Prime	קטן	קתן	כתן	קטג	קון	שיס
	Printed Form	Q*t*n	QTn	KTn	Q*t*G	QWn	SIs
	Phonologic Form	/katan/	/katan/	/katan/	/katag/	/kun/	/shis/
44.	Prime	כמעט	כמעת	קמעת	כמלט	כמיט	סלפי
	Printed Form	KM?*t*	KM?T	QM?T	KML*t*	KMI*t*	sLPI
	Phonologic Form	/kimçat/	/kimçat/	/kimçat/	/kimlat/	/kamit/	/salfi/
45.	Prime	קרחת	קרחט	כרחט	קבחת	קיחת	שלנס
	Printed Form	QRXT	QRX*t*	KRX*t*	QBXT	QIXT	SLNs
	Phonologic Form	/karaxat/	/karaxat/	/karaxat/	/kabaxat/	/kixat/	/shalnas/
46.	Prime	עיתון	עיטון	איטון	עותון	עלתון	צכבזר
	Printed Form	?ITWn	?I*t*Wn	çI*t*Wn	?WTWn	?LTWn	CKBZR
	Phonologic Form	/çiton/	/çiton/	/çiton/	/çoton/	/çalton/	/caxbazar/
47.	Prime	אכזר	אחזר	עחזר	אכזף	איזר	בלוש
	Printed Form	çKZR	çXZR	?XZR	çKZp	çIZR	BLWS
	Phonologic Form	/çaxzar/	/çaxzar/	/çaxzar/	/çaxzaf/	/çizar/	/balush/
48.	Prime	תקליט	תקלית	טקלית	תקליש	תקלשט	בזנרה
	Printed Form	TQLI*t*	TQLIT	*t*QLIT	TQLIS	TQLS*t*	BZNRH
	Phonologic Form	/taklit/	/taklit/	/taklit/	/taklish/	/takleshet/	/baznara/
Nonwords							
1.	Prime	אנליט	אנלית	ענלית	אנליז	אנזלת	מרשדן
	Printed Form	çNLI*t*	çNLIT	?NLIT	çNLIZ	çNLZT	MRSDn
	Phonologic Form	/çanlit/	/çanlit/	/çanlit/	/çanliz/	/çanlezet/	/marshdan/
2.	Prime	אותל	אוטל	עוטל	אותב	ענתל	שקצר
	Printed Form	çWTL	çW*t*L	?W*t*L	çWTB	?NTL	SQCR
	Phonologic Form	/çotel/	/çotel/	/çotel/	/çotev/	/çantal/	/shakcar/
3.	Prime	כנתוש	כנטוש	קנטוש	כנתור	כנתלש	ברמלס
	Printed Form	KNTWS	KN*t*WS	QN*t*WS	KNTWR	KNTLS	BRMLs
	Phonologic Form	/kantosh/	/kantosh/	/kantosh/	/kantor/	/kantlash/	/barmlas/

Appendix F (*continued*)

	Identity (Target)	Homophonic One letter different	Homophonic Two letter different	One phoneme different	Two phoneme different	Control
4. Prime	איטל	איתל	עיתל	איטג	אעשל	מדרף
Printed Form	ςI*t*L	ςITL	?ITL	ςI*t*G	ς?SL	MDRp
Phonologic Form	/ςital/	/ςital/	/ςital/	/ςitag/	/ςeςesal/	/midraf/
5. Prime	לנוכית	לנוכיט	לנוחיט	לנוכיק	לנוכגת	מרצגלב
Printed Form	LNWKIT	LNWKI*t*	LNWXI*t*	LNWKIQ	LNWKGT	MRCGLB
Phonologic Form	/lenoxit/	/lenoxit/	/lenoxit/	/lenoxik/	/lenoxeget/	/marcglav/
6. Prime	קעיף	קאיף	כאיף	קעיל	קעלת	חסנג
Printed Form	Q?Ip	QςIp	KςIp	Q?IL	Q?LT	XsNG
Phonologic Form	/kaςif/	/kaςif/	/kaςif/	/kaςil/	/kaςelet/	/xasnag /
7. Prime	לחיאה	לחיעה	לכיעה	לחירה	לחשרה	במקלר
Printed Form	LXIςH	LXI?H	LKI?H	LXIRH	LXSRH	BMQLR
Phonologic Form	/lexiςa/	/lexiςa/	/lexiςa/	/lexira/	/lexshara/	/bamklar /
8. Prime	תועק	תואק	טואק	תולק	תפעק	פלמז
Printed Form	TW?Q	TWςQ	*t*WςQ	TWLQ	TP?Q	PLMZ
Phonologic Form	/toςek/	/toςek/	/toςek/	/tolek/	/tefςak/	/palmaz/
9. Prime	קזת	קזט	כזט	קזש	קית	פלר
Printed Form	QZT	QZ*t*	KZ*t*	QZS	QIT	PLR
Phonologic Form	/kezet/	/kezet/	/kezet/	/kezesh/	/kit/	/palar/
10. Prime	קדות	קדוט	כדוט	קדוז	קדזת	גשנר
Printed Form	QDWT	QDW*t*	KDW*t*	QDWZ	QDZT	GSNR
Phonologic Form	/kadot/	/kadot/	/kadot/	/kadoz/	/kadezet/	/gashner/
11. Prime	אקית	אקיט	עקיט	אקיד	אקדת	סנפד
Printed Form	ςQIT	ςQI*t*	?QI*t*	ςQID	ςQDT	sNPD
Phonologic Form	/ςakit/	/ςakit/	/ςakit/	/ςakid/	/ςakedet/	/sanfad/
12. Prime	עבטיש	עבתיש	אבתיש	עבטיג	עבטגש	דרנלק
Printed Form	?B*t*IS	?BTIS	ςBTIS	?B*t*IG	?B*t*GS	DRNLQ
Phonologic Form	/ςavatish/	/ςavatish/	/ςavatish/	/ςavatig/	/ςavtagash/	/darnlak/
13. Prime	אשטים	אשתים	עשתים	אשטיר	אשטרם	פלצבר
Printed Form	ςS*t*Im	ςSTIm	?STIm	ςS*t*Ir	ςS*t*Rm	PLCBR
Phonologic Form	/ςashtim/	/ςashtim/	/ςashtim/	/ςashtir/	/ςashtram/	/palcbar/
14. Prime	קאית	קעית	כעיט	קאיד	קאדת	גרנל
Printed Form	QςIT	Q?IT	K?I*t*	QςID	QςDT	GRNL
Phonologic Form	/kaςit/	/kaςit/	/kaςit/	/kaςid/	/kaςedet/	/garnal/
15. Prime	כלמת	כלמט	קלמט	כלסת	כלית	בצנק
Printed Form	KNsT	KNs*t*	QNs*t*	KNsL	KWsT	BCNQ
Phonologic Form	/klemet/	/klemet/	/klemet/	/kleset/	/kalit/	/bacnak/
16. Prime	קחית	קחיט	כחיט	קחיל	קחלת	בדנם
Printed Form	QXIT	QXI*t*	KXI*t*	QXIL	QXLT	BDNm
Phonologic Form	/kaxit/	/kaxit/	/kaxit/	/kaxil/	/kaxelet/	/badnam/
17. Prime	מכתיל	מכטיל	מחטיל	מכתיש	מכתבל	דשזען
Printed Form	MKTIL	MK*t*IL	MX*t*IL	MKTIS	MKTBL	DSZ?n
Phonologic Form	/maxtil/	/maxtil/	/maxtil/	/maxtish/	/maxtabal/	/dashzaςan/

Appendix F (*continued*)

	Identity (Target)	Homophonic One letter different	Homophonic Two letter different	One phoneme different	Two phoneme different	Control
18. Prime	אטליר	אתליר	עתליר	אטלין	אטלנר	חגנזש
Printed Form	ç*t*LIR	çTLIR	?TLIR	ç*t*LIn	ç*t*LNR	XGNZS
Phonologic Form	/çatlir/	/çatlir/	/çatlir/	/çatlin/	/çatlaner/	/xagnezash/
19. Prime	כואר	כוער	קוער	כוחר	כבאר	בסלף
Printed Form	KWçR	KW?R	QW?R	KWXR	KBçR	BsLp
Phonologic Form	/koçer/	/koçer/	/koçer/	/koxer/	/kavçer/	/baslaf/
20. Prime	מחיתה	מחיתא	מחיטא	מחיגה	מחגתה	דרלרע
Printed Form	MXITH	MXITç	MXI*t*ç	MXIGH	MXGTH	DRLR?
Phonologic Form	/mexita/	/mexita/	/mexita/	/mexiga/	/mexgata/	/darlaraç/
21. Prime	קבח	קבך	כבך	קנח	קוח	רזט
Printed Form	QBX	QBk	KBk	QNX	QWX	RZ*t*
Phonologic Form	/kabax/	/kabax/	/kabax/	/kanax/	/koax/	/razat/
22. Prime	כחוז	ככוז	קכוז	כחיז	כחסז	נימץ
Printed Form	KXWZ	KKWZ	QKWZ	KXIZ	KXsZ	NIMc
Phonologic Form	/kaxoz/	/kaxoz/	/kaxoz/	/kaxiz/	/kaxsaz/	/nimec/
23. Prime	עחיט	עחית	אחית	עחיג	עחלט	פגוב
Printed Form	?Xi*t*	?XIT	çXIT	?XIG	?XL*t*	PGWB
Phonologic Form	/çaxit/	/çaxit/	/çaxit/	/çaxig/	/çaxelet/	/pagov/
24. Prime	תרליט	תרלית	טרלית	תרלים	תרלנט	מצושח
Printed Form	TRLI*t*	TRLIT	*t*RLIT	TRLIm	TRLN*t*	MCWSX
Phonologic Form	/tarlit/	/tarlit/	/tarlit/	/tarlim/	/tarlanat/	/mecushax/
25. Prime	אכמנה	אחמנה	עחמנה	אכמדה	אכמוה	בליגר
Printed Form	çKMNH	çXMNH	?XMNH	çKMDH	çKMWH	BLIGR
Phonologic Form	/çaxmana/	/çaxmana/	/çaxmana/	/çaxmada/	/çaxmoça/	/bliger/
26. Prime	תכניר	תחניר	טחניר	תכנור	תכנסר	אלפוש
Printed Form	TKNIR	TXNIR	*t*XNIR	TKNWR	TKNsR	çLPWS
Phonologic Form	/taxnir/	/taxnir/	/taxnir/	/taxnur/	/taxnesar/	/çalpush/
27. Prime	כוכר	כוחר	קוחר	כוכז	כבכר	מטזס
Printed Form	KWKR	KWXR	QWXR	KWKZ	KBKR	M*t*Zs
Phonologic Form	/kokar/	/kokar/	/kokar/	/kokaz/	/kavkar/	/mitzas/
28. Prime	תאליד	תעליד	טעליד	תאלוד	תאבלד	גומסה
Printed Form	TçLID	T?LID	*t*?LID	TçLWD	TçBLD	GWMsH
Phonologic Form	/taçalid/	/taçalid/	/taçalid/	/taçalod/	/taçablad/	/gumsa/
29. Prime	קשיאה	קשיעה	כשיעה	קשינה	קשלנה	רגנפו
Printed Form	QSIçH	QSI?H	KSI?H	QSINH	QSLNH	RGNPW
Phonologic Form	/kshiça/	/kshiça/	/kshiça/	/kshina/	/kshlana/	/ragnafu/
30. Prime	תולח	תולך	טולך	תילח	תרלח	אידר
Printed Form	TWLX	TWLk	*t*WLk	TILX	TRLX	çIDR
Phonologic Form	/tolax/	/tolax/	/tolax/	/tilax/	/tarlax/	/çider/

Appendix F (*continued*)

	Identity (Target)	Homophonic One letter different	Homophonic Two letter different	One phoneme different	Two phoneme different	Control
31. Prime	קטיג	קתיג	כתיג	קטוג	קטמג	זפצב
Printed Form	Q*t*IG	QTIG	KTIG	Q*t*WG	Q*t*MG	ZPCB
Phonologic Form	/katig/	/katig/	/katig/	/katug/	/katmag/	/zafcav/
32. Prime	תמקיש	תמכיש	טמכיש	תמקוש	תמקפש	אצרוז
Printed Form	TMQIS	TMKIS	*t*MKIS	TMQWS	TMQPS	çCRWZ
Phonologic Form	/tamkish/	/tamkish/	/tamkish/	/tamkosh/	/tamkapash/	/çecroz/
33. Prime	קבחת	קבחט	כבחט	קבגת	קבות	לשנג
Printed Form	QBXT	QBX*t*	KBX*t*	QBGS	QBWT	LSNG
Phonologic Form	/kabaxat/	/kabaxat/	/kabaxat/	/kabaget/	/kabot/	/lashang/
34. Prime	כיאד	כיעד	קיעד	כיגד	כסאד	רלמס
Printed Form	KIçD	KI?D	QI?D	KIGD	KsçD	RLMs
Phonologic Form	/kiçad/	/kiçad/	/kiçad/	/kigad/	/kasçad/	/ralmas/
35. Prime	לכאון	לכעון	לחעון	לכדון	לכאדן	פנגסב
Printed Form	LKçWn	LK?Wn	LX?Wn	LKDWn	LKçDn	PNGsB
Phonologic Form	/lixaçon/	/lixaçon/	/lixaçon/	/lixadon/	/lixçadan/	/pangsav/
36. Prime	עתיב	עטיב	אטיב	עתיג	עתגב	רלבן
Printed Form	?TIB	?*t*IB	ç*t*IB	?TIG	?TGB	RLBn
Phonologic Form	/çativ/	/çativ/	/çativ/	/çatig/	/çatgav/	/ralban/
37. Prime	לגאית	לגאיט	לגעיט	לגמית	לגמנת	סמנקד
Printed Form	LGçIT	LGçI*t*	LG?I*t*	LGMIT	LGMNT	sMNQD
Phonologic Form	/lagaçit/	/lagaçit/	/lagaçit/	/lagamit/	/lagmenet/	/samankad/
38. Prime	אטבן	אתבן	עתבן	אטסן	איבן	לגרס
Printed Form	ç*t*Bn	çTBn	?TBn	ç*t*sn	çIBn	LGRs
Phonologic Form	/çetban/	/çetban/	/çetban/	/çetsan/	/çiben/	/lagras/
39. Prime	גחות	גחוט	גכוט	גמוט	גחמת	למגן
Printed Form	GXWT	GXW*t*	GKW*t*	GMW*t*	GXMT	LMGn
Phonologic Form	/gaxot/	/gaxot/	/gaxot/	/gamot/	/gaxemet/	/lamgan/
40. Prime	עתיגה	עטיגה	אטיגה	עדיגה	עתנגה	פרלקס
Printed Form	?TIGH	?*t*IGH	ç*t*IGH	?DIGH	?TNGH	PRLQs
Phonologic Form	/çatiga/	/çatiga/	/çatiga/	/çadiga/	/çatnaga/	/paraleks/
41. Prime	כיגה	כיגא	קיגא	כיצה	כרגה	נלצד
Printed Form	KIGH	KIGç	QIGç	KICH	KNPH	NLCD
Phonologic Form	/kiga/	/kiga/	/kiga/	/kica/	/krega/	/nilcad/
42. Prime	תחביש	תכביש	טכביש	תחביג	תחבלש	הלגמר
Printed Form	TXBIS	TKBIS	*t*KBIS	TXBIn	TXBLS	HLGMR
Phonologic Form	/taxbish/	/taxbish/	/taxbish/	/taxbig/	/taxblash/	/halgmar/
43. Prime	קטס	קתס	כתס	קגס	קטו	שלן
Printed Form	Q*t*s	QTs	KTs	QGs	Q*t*W	SLn
Phonologic Form	/katas/	/katas/	/katas/	/kagas/	/katu/	/shalan/

Appendix F (*continued*)

		Identity (Target)	Homophonic One letter different	Homophonic Two letter different	One phoneme different	Two phoneme different	Control
44.	**Prime**	כנתס	כנטס	קנטס	כלתס	כיתס	סלפי
	Printed Form	KNTs	KN*t*s	QN*t*s	KLTs	KITs	sLPI
	Phonologic Form	/kintes/	/kintes/	/kintes/	/kiltes/	/kites/	/salfi/
45.	**Prime**	קגנת	קגנט	כגנט	קלנת	קגות	שלרס
	Printed Form	QGNT	QGN*t*	KGN*t*	QLNT	QGWT	SLRs
	Phonologic Form	/kagenet/	/kagenet/	/kagenet/	/kalenet/	/kagot/	/shalras/
46.	**Prime**	עיתוס	עיטוס	איטוס	עיגוס	עלתוס	צכבזר
	Printed Form	?ITWs	?I*t*Ws	ςI*t*Ws	?IGWs	?LTWs	CKBZR
	Phonologic Form	/ςitos/	/ςitos/	/ςitos/	/ςigos/	/ςaltos/	/caxbazar/
47.	**Prime**	אכנג	אחנג	עחנג	אלנג	אכיג	בלנש
	Printed Form	ςKNG	ςXNG	?XNG	ςLNG	ςKIG	BLNS
	Phonologic Form	/ςaxnag/	/ςaxnag/	/ςaxnag/	/ςalnag/	/ςaxig/	/balnash/
48.	**Prime**	תגביט	תגבית	טגבית	תגביס	תגבנט	בזנרה
	Printed Form	TGBIt	TGBIT	*t*GBIT	TGBIS	TGBN*t*	BZNRH
	Phonologic Form	/tagbit/	/tagbit/	/tagbit/	/tagbis/	/tagbenet/	/baznara/

References

Berent, I. (1993). The role of assembled phonology in English visual word recognition: Towards a nonlinear model of assembly. Unpublished Doctoral Dissertation, University of Pittsburgh, PA.

Berent, I., & Perfetti, C. A. (1995). Roses are reezes: The two cycles of phonological assembly in English. *Psychological Review, 102*, 146–184.

Berent, I., & van Orden, G. C. (1996). Can we unmask the phonemic masking effect? The problem of methodological divergence. In G. Cottrell (Ed.), *Proceedings of the 18th annual conference of the cognitive science society* (pp. 495–500). Hillsdale, NJ: Erlbaum.

Brysbaert, M. (2001). Prelexical phonological coding of visual words in Dutch: Automatic after all. *Memory & Cognition*.

Brysbaert, M., & Praet, C. (1992). Reading isolated words: No evidence for automatic incorporation of the phonetic code. *Psychological Research, 54*, 91–102.

Cohen, J. (1977). *Statistical power analysis for the behavioral sciences*. Academic Press: New York.

Colombo, L. (2000). The assembly of phonology in Italian and English: Consonants and vowels. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process*. Amsterdam: Elsevier.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Zeigler, J. D. R. C. (2001). A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*, 204–256.

Davis, C., Castles, A., & Lakovidis, E. (1998). Masked homophone and pseudohomophone priming in children and adults. *Language and Cognitive Processes, 13*, 625–651.

Evett, L. J., & Humphreys, G. W. (1981). The use of abstract graphemic information in lexical access. *The Quarterly Journal of Experimental Psychology, 33A*, 325–350.

Ferrand, L., & Grainger, J. (1992). Phonology and orthography in visual word recognition: Evidence from masked nonword priming. *The Quarterly Journal of Experimental Psychology, 45A*, 353–372.

Ferrand, L., & Grainger, J. (1993). The time course of orthographic and phonological code activation in early phases of visual word recognition. *Bulletin of the Psychonomic Society, 31*, 119–122.

Ferrand, L., & Grainger, J. (1994). Effects of orthography are independent of phonology in masked form priming. *The Quarterly Journal of Experimental Psychology, 47A*, 365–382.

Forster, K. I. (1987). Form-priming with masked primes: The best-match hypothesis. In M. Coltheart (Ed.), *Attention & performance XII* (pp. 127–146). Hillsdale, NJ: Erlbaum.

Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Psycholinguistic Research, 27*, 203–233.

Forster, K. I., & Azuma, T. (2000). Masked priming for prefixed words with bound stems: Does submit prime permit? *Language and Cognitive Processes, 15*, 539–562.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 680–698.

Forster, K. I., Davis, C., Schoknecht, C., & Carter, A. (1987). Masked priming with graphemically related forms. Repetition or partial activation? *Quarterly Journal of Experimental Psychology, 30*, 1–25.

Forster, K. I., & Mahoney, C. (unpublished manuscript). Phonological priming with masked primes: Does klip prime CLIP? unpublished manuscript.

Frost, R. (1995). Phonological computation and missing vowels: Mapping lexical involvement in reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 398–408.

Frost, R. (1998). Towards a strong phonological theory of visual word recognition: True issues and false trails. *Psychological Bulletin, 123*, 71–99.

Frost, R., Katz, L., & Bentin, S. (1987). Strategies for visual word recognition and orthographical depth: A multilingual comparison. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 104–115.

Frost, R., Forster, K. I., & Deutsch, A. (1997). What can we learn from the morphology of Hebrew: A masked priming investigation of morphological representation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 829–856.

Frost, R., & Yogev, O. (2001). Orthographic and phonological computation in visual word recognition: Evidence from backward masking in Hebrew. *Psychonomic Bulletin & Review, 8*, 524–530.

Frost, R., Kugler, T., Deutsch, A., & Forster, K. (2001). Orthographic structure versus morphological. structure. Principles of lexical organization in a given language. Paper presented at the 40th Annual Meeting of the Psychonomic Society, Orlando, November, 2001.

Grainger, J., & Ferrand, L. (1996). Masked orthographic and phonological priming in visual word recognition and naming: Cross-task comparisons. *Journal of Memory and Language, 35*, 623–647.

Grainger, J., & Jacobs, A. M. (1991). Masked constituent letter priming in an alphabetic decision task. *European Journal of Cognitive Psychology, 3*, 413–434.

Gronau, N., & Frost, R. (1997). Prelexical phonologic computation in a deep orthography: Evidence from backward masking in Hebrew. *Psychonomic Bulletin & Review, 4*, 107–112.

Hood, D. C., & Finkelstein, M. A. (1986). Sensitivity to light. In K. Boff, L. Kaufman, & J. Thomas (Eds.), *Handbook of perception and human performance* (Vol. 1, pp. 5.1–5.66). New York: Wiley-Interscience.

Humphreys, G. W., Evett, L. J., & Taylor, D. E. (1982). Automatic phonological priming in visual word recognition. *Memory & Cognition, 10*, 576–590.

Humphreys, G. W., Evett, L. J., & Quinlan, P. T. (1990). Orthographic processing in visual word recognition. *Cognitive Psychology, 22*, 517–560.

Jacobs, A. M., Grainger, J., & Ferrand, L. (1995). The incremental priming technique: A method for determining within-condition priming effects. *Perception & Psychophysics*, 1101–1110.

Katz, L., & Frost, R. (1992). Reading in different orthographies: The orthographic depth hypothesis. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 67–84). North-Holland: Elsevier.

Kinsbourne, M., & Warrington, E. K. (1962a). The effect of an after coming pattern on the perception of a brief visual stimuli. *The Quarterly Journal of Experimental Psychology, 14*, 223–224.

Kinsbourne, M., & Warrington, E. K. (1962b). Further studies on the masking of brief visual stimuli by a random pattern. *The Quarterly Journal of Experimental Psychology, 14*, 235–245.

Lukatela, G., Eaton, T., Lee, C., & Turvey, M. T. (2001). Does visual word identification involve a sub-phonemic level? *Cognition, 78*, B41–B52.

Lukatela, G., Frost, S., & Turvey, M. T. (1998). Phonological priming by masked nonword primes in the lexical decision task. *Journal of Memory and Language, 39*, 666–683.

Lukatela, G., & Turvey, M. T. (1994a). Visual access is initially phonological: 1. Evidence from associative priming by words, homophones, and pseudohomophones. *Journal of Experimental Psychology: General, 123*, 107–128.

Lukatela, G., & Turvey, M. T. (1994b). Visual access is initially phonological: 2. Evidence from associative priming by homophones and pseudohomophones. *Journal of Experimental Psychology: General, 123*, 331–353.

Lukatela, G., & Turvey, M. T. (2000a). Do spelling variations affect associative and phonological priming by pseudohomophones? *Perception & Psychophysics, 62*, 196–217.

Lukatela, G., & Turvey, M. T. (2000b). An evaluation of the two-cycles model of phonology assembly. *Journal of Memory and Language, 42*, 183–207.

Michaels, C. F., & Turvey, M. T. (1979). Central sources of visual masking: Indexing structures supporting seeing at a single brief glance. *Psychological Research, 41*, 1–61.

Perfetti, C. A., Bell, L. C., & Delaney, S. M. (1988). Automatic (prelexical) phonetic activation in silent word reading: Evidence from backward masking. *Journal of Memory and Language, 27*, 59–70.

Perfetti, C. A., & Bell, L. C. (1991). Phonemic activation during the first 40 ms of word identification: Evidence from backward masking and masked priming. *Journal of Memory and Language, 30*, 473–485.

Perfetti, C. A., Zhang, S., & Berent, I. (1992). Reading in English and Chinese: Evidence for a universal phonological principle. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 227–248). North-Holland: Elsevier.

Rastle, K., & Coltheart, M. (1998). Whammy and double whammy: The effect of length on nonword reading. *Psychonomic Bulletin & Review, 5*, 277–282.

Shen, D., & Forster, K. I. (1999). Masked phonological priming in reading Chinese words depends on the task. *Language and Cognitive Processes, 14*, 429–460.

Stone, G. O., & van Orden, G. C. (1994). Building a resonance framework for word recognition using design and system principles. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 1248–1268.

Turvey, M. T. (1973). On peripheral and central processes in vision: Inferences from an information-processing analysis of masking with patterned stimuli. *Psychological Review, 80*, 1–52.

van Orden, G. C., & Goldinger, S. D. (1994). The interdependence of form and function in cognitive systems explains perception of printed words. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 1269–1291.

van Orden, G. C., Pennington, B. F., & Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review, 97*, 488–522.

Verstaen, A., Humphreys, G. W., Olson, A., & d'Ydewalle, G. (1995). Are phonemic effects in backward masking evidence for automatic prelexical phonemic activation in visual word recognition? *Journal of Memory and Language, 34*, 335–356.

Xu, P., & Perfetti, C. A. (1999). Nonstrategic subjective treshold effects in phonemic masking. *Memory & Cognition, 27*, 26–36.

Zorzi, M., Houghton, G., & Butterworth, B. (1998). Two routes or one in reading aloud. A connectionist dual-process model. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1131–1161.