

## CHAPTER 12

# Can Theories of Word Recognition Remain Stubbornly Nonphonological?

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The issue of how readers get from the printed word to its lexical representation is a hotly contested one (see Carr & Pollatsek, 1985; Humphreys & Evett, 1985; Van Orden, Pennington, & Stone, 1990, for reviews). Candidate routes are the visual and the phonological. In the visual route, lexical entries are said to be accessed directly on the basis of orthographic properties. The phonological route requires that lexical access be mediated by the recoding of graphemes into their corresponding phonemes. Considerable experimental data have been offered in support of both types of routes. The bulk of research on word identification using English language materials has been taken to implicate the dominance of a visual access route with, perhaps, an optional but not preferred phonological route (e.g., Coltheart, Besner, Jonasson, & Davelaar, 1979; Humphreys & Evett, 1985). Data on word identification using Serbo-Croatian language materials point unequivocally to a nonoptional phonological access route (e.g., Lukatela & Turvey, 1990a, b; Lukatela, Carello, & Turvey, 1990).

We assume that the basic mechanism of written language processing is the same for all languages. Different data patterns among languages, therefore, are to be taken as evidence of how that mechanism can be fine-tuned by the structure of a particular language. We will use some differences and similarities between Serbo-Croatian, English, and Hebrew to elucidate possible features of a written language processing mechanism that would allow such patterns to arise. Given the nature of the data that have been obtained with Serbo-Croatian, such a mechanism must allow for automatic prelexical phonology. Therefore, we must begin with the assumption that all writing systems are phonological—they provide a system for transcribing phonologically any possible word of the language (A. M. Liberman, in press; Mattingly, 1985). The variety of orthographies do this in more or less straightforward ways, resulting in their being phonologically shallow or deep (I. Y. Liberman, A. M. Liberman, Mattingly, & Shankweiler, 1980). How orthographic depth has been interpreted mechanistically will be addressed. We will ultimately claim that the stubborn rejection of phonology in the prevailing theories of reading cannot be sustained within a consistent theory of language processing that accommodates all of the facts, not just those that are convenient (nor, we might add, just those obtained with English).

### Why writing systems must be phonological

As will be shown in later sections, the evidence from experiments in Serbo-Croatian overwhelmingly favors phonological mediation. But our argument begins at a more fundamental level—why that should be an expected outcome. The theoretical backdrop concerns the relation of reading to speech. The basic fact is that phonological structures are the raw materials on which syntactic processes normally work in comprehending speech. These processes are well in place by the time one has to commence the less natural task of learning to read. Given that reading, in contrast to speaking and understanding, is something that must be learned explicitly, how might that be accomplished?

The seemingly sensible strategy for the reader is to use the optical shapes to access phonological structures early in the reading process. Once the reader has done that, he has put the hard part of reading behind him, for everything else will be done automatically by language processes that he commands by virtue of his humanity (A. M. Liberman, 1991, pp. 242-243).

The alternative to this seemingly sensible strategy is that readers concoct nonlinguistic processes that bar them from the ordinary language processor for as long as possible. The effect is that the route that they take to the lexicon and the base representations that they find there are kept—for whatever reason—"stubbornly nonphonological" (A. M. Liberman, 1991, p. 242).

We suspect, instead, that it is reading theorists rather than readers who remain stubbornly nonphonological, both in denying the plausibility of taking advantage of extant phonological processes and overlooking the phonological basis of writing systems. The ultimate constraint on an orthography is that it permit any *possible* utterance in the language to be transcribed—it must respect the allowable phonological forms of the spoken language (determined by its articulatory gestures and their combinations). We note three aspects of how orthographies accomplish this openness (see Mattingly, 1985, this volume). First, orthographies transcribe linguistic units rather than acoustic or phonetic properties which are too context-sensitive. Second, the linguistic units that are transcribed seem to be words, irrespective of how the graphemic units are framed (cf. Wang, 1981). Third, words are transcribed by exploiting the phonological structure of the language, not by using word-specific symbols. This last point is critical for productivity; it allows a systematic way to transcribe novel utterances.

The morphological and phonological structure of a language determine what form this phonological exploitation takes. Alphabetic (or, more generally, segmental) writing systems are more appropriate for languages that "have fairly elaborate syllable structures, large and rather inefficiently exploited inventories of morphemes, and little homophony" (I. Liberman et al., 1980, p. 149). Syllabic writing systems, in contrast, are more appropriate for languages with a small number of syllables (usually with a regular CVCV... structure without consonant clusters). It should be noted that Chinese, despite its reputation in the folklore of orthographies, reflects phonological constraints as well. Its mislabeling as pictographic or ideographic has more to do with socio-cultural agendas than with what is represented by its orthography, namely, syllables (Mattingly, this volume). Logograms are a secondary accompaniment as they must be in a productive, complete writing system (DeFrancis, 1989; Mattingly, this volume; Wang, 1981).

## The orthographic depth hypothesis

Serbo-Croatian, English and Hebrew differ in how straightforwardly their orthographies transcribe the sounds of the spoken language. In Serbo-Croatian, a grapheme such as G is pronounced /g/ regardless of the context in which it appears. There are no irregular pronunciations, silent letters, doubled letters, and so on. In English, G might be pronounced /g/, /j/, or /zh/, or not pronounced at all, depending on whatever else is in the letter string. In Hebrew, vowels are not even represented in 90% of the written material that adults encounter. Homographs are common; the pronunciation of an isolated word depends on which vowels are elected by a reader. This kind of difference has been referred to as orthographic depth<sup>1</sup> (Frost, Katz, & Bentin, 1987; I. Liberman et al., 1980; Lukatela, Popadić, Ognjenović, & Turvey, 1980; Sebastián-Gallés, 1991).

Orthographic depth has been considered relevant to reading because it seems to imply that getting from script to sound is more or less dependable for different languages and, therefore, should be more or less apparent in reading processes. While more or less dependable is fairly well agreed upon, more or less apparent has been subject to some interpretation which we would like to clarify in the context of our recently developed network formulation of Serbo-Croatian word recognition. The theme is that the easier it is to “get to” the sound from the spelling the more likely the reader is to do so in ordinary reading, using that as a basis for getting to other things as well—such as the lexicon. To some, this suggests that readers of a phonologically shallow orthography will access the lexicon phonologically whereas readers of a deep orthography will access the lexicon visually. The reasoning concerns how efficiently articulatory codes are provided. If the translation is complex and takes a long time, they won’t be used (e.g., Frost et al., (1987).

Although not formulated with orthographic depth in mind, dual route theories are consistent with this reasoning. A phonological route to the lexicon is not used in English, it is argued, because the irregularity of script-to-sound makes the translation take too long; visual access, in contrast, is achieved rapidly. A phonological influence will be felt only for those letter strings for which visual access is slowed. This would include nonwords and, perhaps, low frequency words. Under a dual route interpretation, a phonological route to the lexicon would be impossible in Hebrew because the letter strings are so ambiguous.

More recently we have tried to take care in referring to *how apparent* the involvement of phonology is in accessing the lexicon as opposed to *whether or not* it is involved. We are trying to finesse two issues here. One issue has to do with the ease of demonstrating phonological involvement in Serbo-Croatian due to particular methodological advantages (versus processing differences between Serbo-Croatian and deeper orthographies). As noted in detail elsewhere, Serbo-Croatian is not only shallow, it is shallow in two largely distinct but partially overlapping scripts. The nature of the overlap is such that some letters are pronounced the same in the two alphabets while others are pronounced differently depending on which alphabet the reader uses. This allows the construction of letter strings in which a host of properties (semantics, syntax, frequency, associative relatedness) can be controlled experimentally while distinguishing graphemic from phonemic similarity. If experiments in English or Hebrew could be similarly contrived, they might, in principle, show unequivocal phonological involvement as well.

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<sup>1</sup>Orthographic depth, in fact, has a second aspect and that is the relative remoteness of the phonetic representation from the morphophonological representation (I. Liberman et al., 1980). Experimental investigations that deal with orthographic depth tend to focus only on how easily the orthography approximates the phonetic representation.

The second issue concerns the mechanistic interpretation of orthographic depth. The tradition has been to couch it in terms of discrete grapheme-phoneme correspondence rules or GPCs. More recent models, such as those pioneered by McClelland and Rumelhart (1986) and envisioned by Van Orden et al. (1990), could accommodate (in principle) orthographic depth with respect to the strength and number of connections in a parallel distributed network. Distinctions between these two kinds of approaches will be considered in some detail before turning to experimental demonstrations of phonological involvement in word recognition.

### Mechanistic interpretations of orthographic depth

Grapheme-phoneme correspondence rules constitute the more familiar treatment of how one gets from spelling to sound (e.g., Coltheart, 1977, 1978). They specify how particular letters or clusters of letters are to be pronounced. And they do so discretely; the rules do not vary in strength. Thus, under this treatment, a shallow orthography is one that has relatively few rules and whose words can be relied upon to follow them (e.g., in Serbo-Croatian, the rules are defined at the level of the individual grapheme because their pronunciation is not changed by being combined with different combinations of graphemes). A deep orthography may have numerous rules or exceptions to its rules (e.g., in English, when a word ends in E, the E is silent and the preceding vowel is long; CAVE obeys this but HAVE does not) or, perhaps, application of its rules is simply inadequate to allow a reader to settle on a single pronunciation (e.g., in Hebrew, the standard printed form omits vowel marks so that a particular letter string can be pronounced as different words depending on which vowels are elected). However reliable they are, GPCs more or less embody what is orthographically legal in a given language. (This fact is responsible for the easy link between GPCs and pseudowords: GPCs may be useful at least insofar as they permit one to pronounce a novel letter string.)

Under the discrete symbol, rule-based characterization of assembling phonology, it is possible to consider that readers of different kinds of orthographies are engaging in different kinds of processes. Those for whom GPCs are reliable would be well-served to try them since a straightforward translation might be faster than a lexical search for a visual match to the orthographic pattern. But those for whom GPCs are unreliable or inadequate might be forced to be visual readers since using the rules would be slow and error prone. Visual readers, then, would be engaged in a search for a word-specific match in the lexicon.<sup>2</sup> Novel letter strings might allow them to apply GPCs but don't require it; a pronunciation can be generated by (visual) analogy to a real word (e.g., Glushko, 1979; Kay & Marcel, 1981).

But the possibility of a persisting visual route (i.e., all the way to the lexicon) ignores the phonological foundation of writing systems and delays the reader's tapping into the language machinery set up to understand speech. Simply on logical grounds, it is unsavory. Rather than considering that orthographic depth contributes to the formation of different language processing devices, one that is rule-based and one that is word-specific, let us consider that orthographic depth serves to modulate the same basic device. A parallel distributed network is a candidate device amenable to such modification. The network consists of successive, connected layers of subsymbolic nodes (see Lukatela,

<sup>2</sup>Van Orden et al. (1990) point out that the way in which the debate has been framed has had the insidious effect of turning psycholinguistics into what it had originally criticized: An account of verbal behavior rooted in specific stimulus-response connections.



Feldman, Turvey, Carello, & Katz, 1989, and Lukatela Turvey, Feldman, Carello, & Katz, 1989, for detailed descriptions of the network for Serbo-Croatian). The connections reflect covariation (e.g., between orthographic features and phonological features) and statistical regularity (they are weighted) rather than discrete rules. In other words, they are modifiable. Orthographic depth modulates this device with respect to the number and strength of these connections. Processing differences among languages, then, are not so much qualitative as quantitative: In Serbo-Croatian, the letter-phoneme connections are few and strong; in English, they are many and weak. The ultimate effect on response time, of course, may be qualitative because the pattern of activation emerges from a dynamical system in which linear changes can have nonlinear consequences.

This interpretation of orthographic depth means that there is only one kind of processing. Indeed, parallel distributed networks destroy the basis for considering "routes" to the lexicon as if they were independent pathways with no mingling of activation. At bottom, they allow us to reject the dual route model altogether, including its logic for inferring nonphonology.

### **The logic of inferring nonphonology in the absence of a dual route theory**

In the logic of dual-route theory, lexical context effects are thought to undermine the case for assembled phonology. Since rules are discrete, not graded, things like frequency should not matter: K should be pronounced /k/ whether it appears in KICK or KALE. If the higher frequency word is pronounced faster, it must be because its visual form is more familiar. But in an interactive network, the lower threshold of high frequency word units means that they would be activated sooner by the pattern of excitation arising through the phoneme unit level. Indeed, with communication between levels, many lexical properties can be expected to influence pronunciation. Automatic involvement of the lexicon is inevitable given the bi-alphabetic nature of Serbo-Croatian. The presence of phonologically ambiguous letters generates activity along two letter-phoneme connections. If there are, say, two phonologically ambiguous letters in a four letter word, four pronunciations of that letter string are assembled. Each gives rise to some activation at the word unit level depending on how closely the phonemes match the word unit (with respect to number and order) and on the word units' frequencies. Activation of certain word units is strengthened by interaction between word and phoneme levels and continues until above-threshold activation of a single word unit emerges. Of course, this interactive processing is not limited to phonologically ambiguous words; it is characteristic of the ordinary language processor. Phonologically unique letter strings generate a single code but it partially activates a number of word units. Although a single word unit emerges quickly from interaction between word and phoneme levels, interactive processes nonetheless provide the opportunity for lexical influences on pronunciations assembled on the basis of prelexical phonology. That is to say, phonological codes are assembled by the prelexical phonological connections but a single pronunciation is settled on out of the global pattern of activation. Lexical involvement does not contravene prelexical phonology (Carello, Lukatela, & Turvey, under review).

Relatedly, we argue that the distinction between assembled and accessed phonology has been cut too sharply, as if phonological information came only from one source or the other. To arrive at the lexicon phonologically does not mean that the assembled code carries every phonological nuance. Linguistic features such as stress and prosody must be derived from the phonological representation in the lexicon which has itself been accessed

via prelexical phonological connections. For example, the stress pattern of Serbo-Croatian words—which is not marked in the orthography—can be rising or falling and long or short. In addition, although the first syllable is usually stressed, occasionally the second syllable is stressed instead. A correct pronunciation requires information about the stress pattern which can only be had at the word unit level. But information about the stress pattern is only made available once the word unit has been activated by the phonological code. That is to say, the existence of accessed phonology does not contravene prelexical phonology (see Lukatela & Turvey, 1990, for experimental ramifications of differing stress patterns between contexts and targets).

### **The logic of inferring phonology**

The case for prelexical phonology is, at the very least, not undercut by the existence of lexical context effects. But what kind of evidence would make the case for prelexical phonology? If we invert the logic that has been established by those advocating primacy of the word-specific visual route, we can look for several things. Phonological influences should be observed on acceptance latencies (which are, by and large, faster than rejection latencies), especially on high frequency words. Such evidence would support the claim that the influence is felt in ordinary word recognition, not just for letter strings that have no lexical entries (cf. Coltheart, Davelaar, Jonasson, & Besner, 1977; Kay & Marcel, 1981). Phonological effects should be apparent in both naming and lexical decision. Naming is important because it is supposed to be free of post-lexical influences (Balota & Chumbley, 1985; West & Stanovich, 1982). The effect ought to depend on the number of constituents (letters, syllables) in a word. A phonologically analytic process would reflect the burden of decoding details of the orthographic structure (Green & Shallice, 1976). Phonological effects should persist in the face of experimental conditions that discourage the use of prelexical phonology. Strategic insensitivity would suggest that the phonological route is nonoptional (cf. Hawkins, Reicher, Rogers, & Peterson, 1976). Finally, phonological effects must appear over and above effects due to graphemic similarity. Orthographically similar rhyming items should behave the same as orthographically dissimilar rhyming items but different from orthographically similar nonrhyming items (cf. Evett & Humphreys, 1981).

### **The case for prelexical phonology in Serbo-Croatian**

The case for prelexical phonology has been made on each of these points using the Serbo-Croatian language. These results can be organized around three general manipulations permitted by exploiting the two alphabets: (1) comparisons between phonologically unique letter strings, composed exclusively of unique and common letters, and phonologically ambiguous letter strings, composed exclusively of common and ambiguous letters; (2) comparisons of phonemically and graphemically similar pairs, written in the same alphabet, and phonemically similar but graphemically dissimilar pairs, with the context and target written in different alphabets; and (3) comparisons of phonologically ambiguous pseudowords in which a mixed interpretation of the letters in a single letter string either is or is not a word.

Manipulations of the first type produce the so-called Phonological Ambiguity Effect—letter strings with more than one phonological interpretation are associated with longer latencies and higher errors than letter strings with only one phonological interpretation

*even though they are the same words.* For example, VETAR and BETAP are Roman and Cyrillic, respectively, for "the wind." VETAR has one phonological interpretation, /vetar/, because V and R are uniquely Roman letters and E, T, and A are common. BETAP, in contrast, has four phonological interpretations because B and P can be read (differently) in Roman and Cyrillic. The Cyrillic interpretation of both yields /vetar/. The Phonological Ambiguity Effect occurs in naming and lexical decision (e.g., Lukatela, Feldman et al., 1989; Lukatela, Turvey et al., 1989), is larger for words (independent of frequency) than pseudowords (e.g., Feldman & Turvey, 1983; Lukatela, Feldman, et al., 1989), increases with more phonologically ambiguous letters (Feldman, Kostić, Lukatela, & Turvey, 1983; Feldman & Turvey, 1983), decreases with more unique letters (Lukatela, Feldman, et al., 1989), and persists despite instructions (Lukatela, Savić, Gligorijević, Ognjenović, & Turvey, 1978) or experience favoring one alphabet (Feldman & Turvey, 1983) or discouraging phonological coding (Lukatela, Feldman, et al., 1989).

Manipulations of the second type produce phonemic similarity effects. Naming latencies to the word target PUŽIĆ (/puzhich/) and the pseudoword target PUDIĆ (/pudich/) are facilitated to the same degree by phonemically similar contexts, whether those are graphemically similar (PUTIĆ, /putich/) or dissimilar (ПУТЏИЋ, /putich/) (Lukatela & Turvey, 1990a). For lexical decision latencies, the direction of the phonemic similarity effect depends on target frequency, the ordinal position of the distinguishing phoneme, and lexicality. Phonemic similarity effects persist even when the context is masked (for both word-pseudoword and pseudoword-word sequences, Lukatela & Turvey, 1990a), and when graphemic similarity is further reduced by writing contexts in lower case and targets in upper case, for example, pasus-ПАСУЉ, /pasus-pasulj/ (Lukatela et al., 1990). Finally, target identification under conditions of backward masking—a target followed by a pseudoword mask which is itself followed by a pattern mask—is enhanced when the pseudoword mask is phonologically similar to the target (Lukatela & Turvey, 1990b). The mask presumably continues activation at the phoneme unit level that had been initiated by the target (Naish, 1980; Perfetti, Bell, & Delaney, 1988).

Manipulations of the third type produce "virtual word" effects. BEMAP and HAPEM both differ from a real word by one letter (BETAP and XAPEM, respectively). B, P, and H have different interpretations in Roman and Cyrillic so that a phonologically analytic processing of each string would produce four codes. For BEMAP none of these is a word, whereas for HAPEM one is a word. HAPEM-type strings produce a much larger false positive error rate: 30% vs. 3%. When a HAPEM-type follows a context associatively related to the virtual word interpretation, false positives increase to 55%, compared to 7% for BEMAP-types following associates of their source words (Lukatela, Feldman, et al., 1989; Lukatela, Turvey, et al., 1989). In naming, the mixed alphabet (virtual word) interpretation of HAPEM-type strings occurred 3-4 times more often than the mixed alphabet interpretation of BEMAP-types. These differences arise even though the two types of pseudowords are equally similar visually to a real word—they differ by one letter. But whereas every code for BEMAP is also one phoneme different from a real word, one code for HAPEM shares all phonemes with a real word. Virtual word effects derive from prelexical phonology.

For Serbo-Croatian, in sum, the requisite patterns of results have been obtained to allow the conclusion of prelexical phonology. Phonological involvement has been demonstrated on "yes" responses, with high frequency words, on words more than pseudowords, in naming as well as lexical decision; it is sensitive to the number of constituents, and

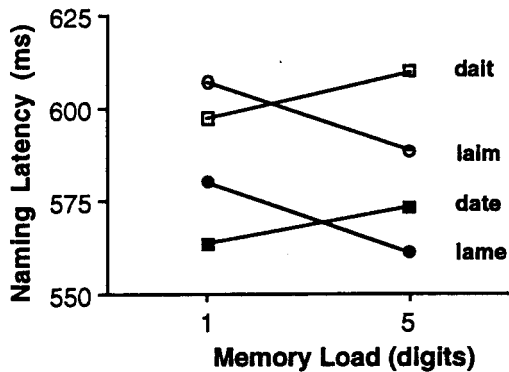
persists despite experimental conditions that might discourage it; finally, phonological effects are independent of graphemic effects which, in fact, do not occur. The results from English and Hebrew do not permit quite the same point by point confirmation. But there are what we might consider "existence proofs" for a number of them.

### The case for prelexical phonology in English

The supporting English results can be organized around four general manipulations, the first three of which exploit the deep orthography: (1) comparisons between pseudohomophones, nonwords that are pronounced the same as real words but spelled differently, and spelling controls, nonwords that differ from the targets by the same number of letters as the pseudohomophone but are pronounced differently; (2) comparisons between homophones, words that are pronounced the same as target words but spelled differently, and spelling controls; (3) comparisons of phonologically consistent pairs in which a given stem receives the same phonological interpretation, and phonologically inconsistent pairs in which a given stem receives different phonological interpretations; and (4) comparisons of phonemically and graphemically similar pairs, phonemically similar and graphemically dissimilar pairs, and graphemically similar but phonemically dissimilar pairs.

Manipulations of the first type provided some of the earliest suggestions of phonological involvement in lexical decision (e.g., Rubenstein, Lewis, & Rubenstein, 1971). But since this effect was on "no" responses which are already slow, delayed rejections of pseudohomophones was soon interpreted as implicating phonological involvement only when the direct route hadn't worked fast enough (see Van Orden et al., 1990, for a rebuttal of the logic behind the so-called "delayed phonology hypothesis"). Not prone to such an indictment are recent experiments showing associative priming by and of pseudohomophones: TABLE facilitated the naming of the pseudohomophone CHARE relative to the spelling control CHARK; the pseudohomophone prime TAYBLE facilitated the naming of CHAIR relative to the spelling control prime TARBLE (Lukatela & Turvey, 1991). In both of these instances, in order for the associative relationship to have had an effect, the lexicon must have been accessed and it must have been accessed through phonology. In four experiments, the graphemic control did not produce a significant effect (and the numerical difference was always in the wrong direction). In contrast, TAYBLE did not differ from TABLE in its effect on naming CHAIR. Moreover, the word targets (and source words of the pseudohomophones) were of relatively high frequency (217 according to the norms of Francis & Kučera, 1982).

Other experiments have demonstrated additional dimensions of equivalency in the processing of pseudohomophones and their real word counterparts (Lukatela & Turvey, in press). Between the presentation and recall of one or five digits, subjects performed a secondary task of naming a visually presented letter string—a pseudohomophone (e.g., FOLE, HOAP) or its lexical counterpart (FOAL, HOPE). If nonwords are named by a slow (resource expensive) process that assembles the letter string's phonology and words are named by a fast (resource inexpensive) process that accesses lexical phonology (see Paap & Noel, 1991), then memory load should interact with lexicality (HOPE vs. HOAP, FOAL vs. FOLE). To the contrary, three experiments found that load interacted only with frequency (HOPE vs. FOAL, HOAP vs. FOLE), suggesting that pseudohomophones and their word counterparts are processed similarly, namely, phonologically. An example of the form of the interaction is shown in Figure 1. In a fourth experiment the associative priming-of-naming task described above was secondary to the memory task.



*Figure 1.* High frequency words and their pseudohomophones (closed and open squares, respectively) are hindered by increased memory load. The opposite pattern is obtained with low frequency words and their pseudohomophones (closed and open circles, respectively). That is, words are more similar to their nonlexical but phonologically identical counterparts than they are to each other.

In elaboration of Lukatela and Turvey's (1991) observations, associative priming (HOPE-DESPAIR, FOAL-HORSE) was equaled by pseudohomophone associative priming (HOAP-DESPAIR, FOLE-HORSE) with memory load affecting both kinds of priming in the same way.

Manipulations of the second type show homophony effects on rejection latencies, this time in semantic categorization tasks: BEATS takes longer to reject as a member of the category VEGETABLE than do other foils (e.g., Meyer & Ruddy, 1973). Finer analyses, however, reveal homophony to be influential on faster yes responses as well: The false positive error rate is higher for homophones than for spelling controls (18.5% vs. 3.0%, Van Orden, 1987) and the false positive "yes" latencies are comparable to the correct "yes" latencies (Van Orden, Johnston, & Hale, 1988). Moreover, although orthographic similarity of homophones (BEATS is more like BEETS than ROWS is like ROSE) matters under unmasked conditions, the orthographic effect disappears when targets are pattern-masked while the homophony effect remains strong (Van Orden, 1987). Van Orden argues that this supports the role of phonological mediation as an early source of constraint on word identification (Van Orden, 1987; Van Orden et al., 1990).

Manipulations of the third type show differences in priming effects between graphemically similar pairs that are also phonologically similar (BRIBE-TRIBE) and graphemically similar pairs that are phonologically dissimilar (TOUCH-COUCH). Generally, phonological consistency is beneficial and phonological inconsistency is detrimental (Hanson & Fowler, 1987; Meyer, Schvaneveldt, & Ruddy, 1974). Where there are priming effects for both types of pairs, the effect with phonologically similar pairs is greater (Hanson & Fowler, 1987). Even the results of Evett and Humphreys (1981), who did not find differences due to consistency when the primes were masked, have been interpreted as supportive of phonological mediation by "noisy phonologic codes" (Van Orden et al., 1990, p. 495). The epithet noisy is applied on the assumption

that TOUCH would give rise to a code that had elements of both /tutch/ and /towtch/.<sup>3</sup> Therefore, priming of COUCH by TOUCH is, in fact, a phonological effect. Van Orden (1987; Van Orden et al., 1990) argues further that sometimes noisy codes are sufficient to distinguish words from nonwords (e.g., when the pseudoword foils are illegal nonwords), in which case there would be no advantage for phonologically consistent pairs. Phonological inconsistency will be detrimental when noisy codes must be cleaned up, viz., for foils that are legal nonwords. These are the results reported by Shulman, Hornak, and Sanders (1978) and Hanson and Fowler (1987). Interestingly, detrimental phonological inconsistency effects—those historically taken to demonstrate phonological mediation—are most likely under experimental conditions that ought to discourage phonology were it optional (Van Orden et al., 1990). That is to say, with legal nonword foils, words would be better distinguished by a graphemic code were it an option.

Manipulations of the fourth type have produced inconsistent results. While facilitation for phonemically similar, graphemically dissimilar pairs has been reported (Hillinger, 1980), this has not been replicated, either in lexical decision (Martin & Jensen, 1988) or naming (Peter, Turvey, & Lukatela, 1990). But graphemic priming was not found either. As an important aside, we note that this latter result would appear to be in sharp contradiction of the major expectation from the hypothesized visual, word-specific route. If lexical items are coded visually (more precisely, orthographically), then preceding words that are visually similar to immediately subsequent words should facilitate decisions on the immediately subsequent words. That such visually based facilitation is difficult to obtain (ordinarily investigators have to impose a number of additional manipulations, such as severe forward masking of the prime, to reveal slight effects [e.g., Forster, 1987]) should be taken as *prima facie* evidence that visual access is neither prominent nor particularly straightforward. Curiously, proponents of the visual, word-specific route have been mute on this failure to prime the lexicon visually.

More reliable than the results from forward phonemic priming are results from masked backward priming (a target followed by a pseudoword mask which is itself followed by a pattern mask): Targets are more likely to be identified when the pseudoword mask is phonemically rather than graphemically similar to it (Naish, 1980; Perfetti et al., 1988). Manipulations of this fourth type can be combined with those of the second type. ROWS is more likely to be recognized as a member of the category FLOWER when followed by a phonemically similar rather than graphemically similar pseudoword mask (Peter & Turvey, 1992).

In sum, the results for English are accumulating to allow the conclusion of prelexical phonology. Phonological involvement has been demonstrated on “yes” responses, with high frequency words, and in naming as well as lexical decision; it has occurred despite experimental conditions that might discourage it; and, finally, phonological effects have been obtained that are over and above graphemic effects which are, in fact, unreliable.

### The case for prelexical phonology in Hebrew

Our assertion that the underlying processing is the same across languages requires that there be at least some evidence of prelexical phonology in the deepest orthographies. The phoneme layer still exists even though the letter to phoneme connections might be multiple and very weak. Support for phonological involvement in Hebrew comes from

<sup>3</sup>This is not unlike what we have proposed for phonologically ambiguous letter strings in Serbo-Croatian—all possible pronunciations of a string are generated before one is settled on through competitive processes.

two general manipulations that exploit the fact that vowels are not represented in ordinary text: (1) comparisons of pointed and unpointed letter strings, and (2) comparisons of phonologically ambiguous and unambiguous words.

Manipulations of the first type provided the earliest suggestion of phonological mediation in Hebrew. For some consonant strings, there is only one phonological interpretation with a single lexical entry. Adding the proper vowels redundantly specifies the same pronunciation. Adding certain incorrect vowels specifies other particular pronunciations that are phonotactically legal even though they are without a lexical entry. Adding other incorrect vowels that are allophonic with the correct vowels will specify the correct pronunciation even though that orthographic pattern has no lexical counterpart (it is a pseudohomophone). Navon and Shimron (1981) found that allophonically voweled letter strings (essentially pseudohomophones) did not differ in naming time from ordinary unpointed or correctly pointed letter strings. That is, the correct phonological interpretation accessed its lexical entry even though its orthographic form was novel. Naming was slower when the added vowels specified a pronunciation without a lexical entry. More recently, it has been shown that readers will wait for the vowel marks in a delayed presentation paradigm (consonant string followed at some lag by the diacriticals) even though the orthographic form has only one lexical entry (Frost, 1992). This was true for both high and low frequency words in both lexical decision and naming.

Manipulations of the second type are somewhat similar to manipulations of phonological ambiguity in Serbo-Croatian in that a given letter string can be pronounced in more than one way. In this case, the phonological options come not from choice of alphabet but from choice of vowels to assign to an unpointed letter string. Here we consider only those pronunciations that constitute words (rather than all pronunciations that might be generated by the random assignment of vowels). Consonant strings with three or more phonemic realizations are named more slowly than consonant strings with only one (Bentin, Bargai, & Katz, 1984). When semantic priming contexts are consonant strings with two phonemic realizations and two meanings, one a high frequency word and one a low frequency word, lexical decision is facilitated more by the phonological interpretation associated with the higher frequency word (Frost & Bentin, 1992). When these same letter strings are pointed (and, therefore, phonologically unambiguous), the amount of facilitation by the low and high frequency versions is the same. Relatedly, contexts with both a high and low frequency meaning but with a single phonological interpretation (like the English word RUN, for example) also produce equivalent facilitation in targets semantically related to either of the two meanings. Taken together, these findings suggest that the ambiguity effect found with heterophonic homographs is phonological rather than semantic in origin (Frost & Bentin, 1992). Delaying the onset of vowel marks after the presentation of ambiguous letter strings with two phonemic realizations slows the naming of words (both high and low frequency) and pseudowords equally (Frost, 1992). This lag effect is larger than that for unambiguous words.

The results for Hebrew suggest at least some involvement of prelexical phonology. It has been demonstrated on "yes" responses, with high frequency words, and in naming as well as lexical decision; it has occurred despite experimental conditions that do not require it; and one phonological effect has been obtained that is over and above a graphemic effect. But the body of data from Hebrew are equivocal, perhaps epitomized by the fact that lexical decision to targets either orthographically or phonemically similar to pseudoword primes are facilitated to the same degree (Bentin et al., 1984).

Nonetheless, the extent of parallel evidence in Serbo-Croatian, English, and Hebrew is impressive. The script-sound relationships in the three languages constitute very different experimental settings. Some of the classes of experiments that we have discussed are not possible in the other language. English and Hebrew have no mixed alphabets; Serbo-Croatian has no phonological inconsistency. For the most part, the differences favor Serbo-Croatian as a vehicle for demonstrating prelexical phonology (Lukatela et al., 1990; Lukatela & Turvey, 1990 a, b). Despite these differences, early nonoptional phonological involvement is apparent in all. Differences that remain are arguably due to differences in covariant learning particularly with respect to letter-phoneme connections.

### **Concluding remarks: The primacy of phonological “dynamics”**

We have chosen to build our arguments for reading's natural phonological basis around a hypothesis of prelexical phonology as primary. Roughly interpreted, this hypothesis is that processes intimately connected to those by which speech is produced and perceived constitute the major constraint on the mapping from print to lexicon. The now classic dual-route theory has provided a fairly simple (and empirically fruitful) framework within which to deliberate how a person's knowledge about words might be tapped by letter strings: It is tapped either by the letter strings described in the predicates of the visual system, or by letter strings described in the predicates of the speech system, or both. As the theory tends to go, the visual predicates are more prominent than the speech predicates. Our arguments in this chapter were phrased very much in the context of the dual-route theory, and in reaction to the proposed primacy of visual predicates. The strategy we adopted was chosen because, in many respects, it is the most convenient and the most conducive to communication (relying as it does upon the most conventional understanding). In these final remarks, however, we would like to take a more critical and circumspect stance. We explore the implications of a continuous dynamical perspective on word-recognition processes, the perspective adumbrated in much of the foregoing criticism of the “stubbornly nonphonological” accounts.

Our departure point is an assertion: Learning to read is largely an autonomous process. By this assertion we intend to mean several things. First, reading is achieved by a system capable of attuning to mappings between orthographic and linguistic structures, however arbitrarily complex those mappings might happen to be (that is, it does not require that the mappings be orthogonal or linearly separable). Second, the structures mapped between are characterized by distinguishable features or substructures at many grain sizes; there is, however, no biasing of the system toward any particular grain size. Consequently, attunement may occur to mappings that vary considerably in the sizes of the substructures comprising their domains and codomains. Third, the system's attunement is eventually most pronounced (but not exclusively restricted) to the mappings significant to reading without having to be informed explicitly as to what those particular significant mappings might be. Fourth, the enhanced attunement to reading-significant mappings follows from a generic selection principle: Those mappings are selected that are single-valued, or most nearly so. That is, the more invariant the relation between particular substructures of the orthography and particular linguistic substructures, the more likely is it that that mapping will be selectively enhanced.

In dynamical terms, what are the consequences of invariance—of single-valuedness? An approximate answer, one highlighted by Van Orden et al. (1990), is that resonance or self-consistency is achieved rapidly within the connective matrix binding (the processing



units of) the domain's and codomain's substructures. Borrowing from adaptive resonance theory (Grossberg, 1987; Grossberg & Stone, 1986), a resonant mode is achieved when the activity excited in a given layer of processing units from below matches that excited from above. A closely related answer is that the pattern of activity engendered in the network instantiation of the mapping is stable. Consequently, where a mapping deviates from single-valuedness, the time course of achieving resonance is slower and/or the final-state stability is less.

In most languages, if not all, the invariance is greatest between orthography and phonology, roughly speaking, between the spellings of words and the names of words. Patently, the mappings between orthography and the meanings of words, and orthography and the syntactic functions of words, are considerably less consistent. Phonological representations will, therefore, achieve resonance faster, and reach states of stability greater, than other linguistic representations. Again, in terms of adaptive resonance theory, a greater match is achieved, and achieved at a more rapid pace, between the activity patterns in the phonological layer excited by (a) the lexical layer above, and (b) the graphemic layer below. The upshot is that even if many activations of linguistic substructures by orthographic substructures occur concurrently in word recognition, it is the phonological activation that stabilizes earliest, providing a basis for stabilizing the other patterns of linguistic activation (Van Orden et al., 1990).

In these final remarks we have pursued a line of argument constrained by the notions of autonomy and invariant. We have been led to conclude that, in word recognition, the dynamics associated with phonological processes are primary. It will be interesting to see in what directions a theory grounded in dynamics might evolve (along the lines, perhaps, of recent efforts in movement coordination, e.g., Kugler & Turvey, 1987; Schmidt, Beek, Treffner, & Turvey, 1991; Turvey, 1990; Turvey, Schmidt, & Beek, in press) and the kinds of experimental hypotheses to which it might give rise. A benchmark for evaluating such a theory's worth is the dual process theory, which has been the dominant source of stimulation for research on word recognition in recent times. Will a dynamically based theory be as fruitful?

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