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Reading in Two Alphabets

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Many speakers of Serbo-Croatian read the language in two phonemically precise and partially overlapping alphabets. Twenty years of experiments directed toward this ability have led to deeper understandings of the role of speech-related processes in reading and the contrasts and similarities among the world's alphabetic writing systems.

The writing system used to transcribe the language referred to traditionally as Serbo-Croatian was constructed in the nineteenth century through the efforts of Vuk Karadžić and (later) Ljudevit Gaj and Ivan Broz. It was constructed on the basis of a simple rule proposed by Karadžić in 1814: "Write as you speak and read as it is written." Accordingly, all written letters are pronounced and the only restrictions on how letters are sequenced in a word are those restrictions that apply to the sounds of the spoken language.

The situation is very different in English. Silent and double letters are common, and included among the various constraints on letter sequences are spelling conventions (e.g., *gh* pronounced "eff" as in rough) and conventions designed to ensure that a word's relation to other words of similar meaning is evident in the writing despite grave differences in pronunciation (e.g., *anxious* and *anxiety*; e.g., Gleitman & Rozin, 1977). Whereas illegal sound sequences can never be transcribed in Serbo-Croatian, they are frequently transcribed in English, for example, *wh*. Not surprisingly, perhaps, the misreadings by beginning readers of Serbo-Croatian do not reproduce in all details the misreadings of beginning readers of English. For example, beginning readers of Serbo-Croatian contrast with their English language counterparts in committing fewer errors on vowels than on consonants but share with them the tendency to misread final consonants more so than initial consonants (Ognjenović, Lukatela, Feldman, & Turvey, 1983).

In constructing what was to become the modern writing system, many of the letters in the old alphabet were used together with a number of letters borrowed and modified from other alphabets. The goal, identified by Karadžić, was to represent graphically each of the basic sounds or phonemes of the language, and for this purpose more letters were needed than the old alphabet provided. Of special significance is the fact that two new alphabets were constructed to represent the 30 phonemes—a Cyrillic alphabet (through the original efforts of Karadžić) and a Roman alphabet (through the later efforts of Gaj and Broz) suited, respectively, to the cultures of eastern and western speakers of Serbo-Croatian (see Figure 1). Most of the letters they chose were unique to one alphabet or the other. Of the letters they included in both alphabets, some represented the same speech sound but others were ambiguous, representing one sound in the Roman alphabet and a different sound in the Cyrillic alphabet. For example, the letter *P* shared by the two alphabets is pronounced in Roman like the letter *P* in English and is pronounced in Cyrillic like the letter *R* in English. Consequently, for a reader of Serbo-Croatian fluent in both alphabets, the word *potop*, with the shared unambiguous letter *o*, is pronounceable in two ways with two different meanings (*deluge* in Roman and *rotor* in Cyrillic).

For many scientists investigating human cognitive abilities, a question of major importance is how a person can look at a printed word and know fairly immediately its meaning and pronunciation. From the point of view of theory, the question entails issues of how the brain transforms visual patterns into language codes and how the memories for words are organized and retrieved. From a practical viewpoint, the question bears on the problem of literacy, in particular the issue of whether the teaching of reading should focus on how printed words look (assuming that meaning is retrieved by a visual code) or on how printed words sound (assuming that meaning is retrieved by a phoneme-based code). Although it was hardly the intent of Karadžić or Gaj and

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Broz, their creation of two phonemically and partially overlapping alphabets for the same language has proven to be a godsend to present day experimentalists seeking an answer to the question of how a person recognizes words.

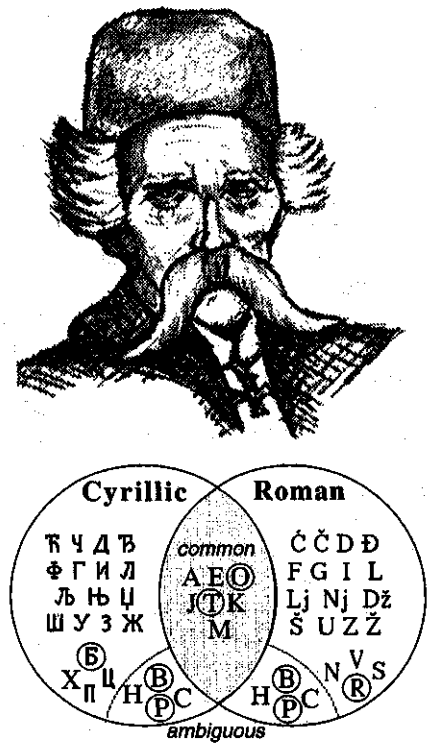
Readers of Serbo-Croatian who are experts in both alphabets are equipped, by education, with two sets of visual symbols and two sets of strict letter-to-phoneme correspondences that they can use freely in reading books, newspapers, street signs, shop names, and so on, printed in either one alphabet or the other and, in some cases, printed twice, once in each alphabet. However, because of this expertise, the reader is susceptible to a unique problem. When facing a word such as *potop,* the automatic application of the reader's codes can generate (and, as will become apparent, do generate) four pronunciations: /potop/, /rotop/, /potor/, and /rotor/. This ambiguity arises from the phonemic precision of the Serbo-Croatian writing systems and is, therefore, different in origin and, perhaps, in kind, from the ambiguity experienced by a skilled reader of English confronting words such as *pint, have,* and the like. The latter ambiguity (*pint* could be spoken like *mint*; *have* could be spoken like *wave*) arises because of the phonemic imprecision of the English writing system. As observed above, the historical development of English script was shaped very much by the concern that words of similar meaning should be spelled similarly even though they might not sound similar (like *anxious* and *anxiety, heal* and *health*).

Order of Learning

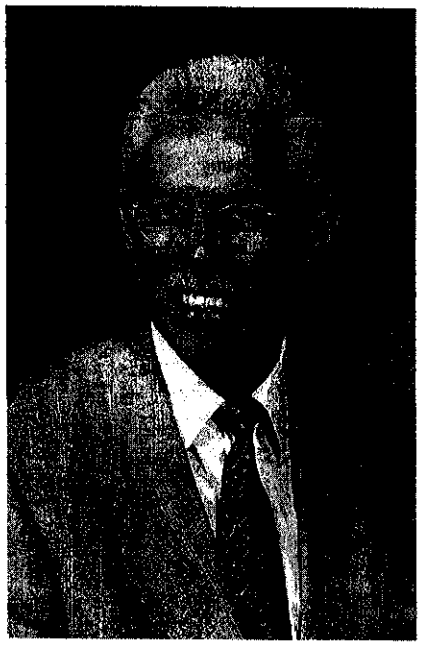
Prior to the recent conflict among the former republics of Yugoslavia, it was customary for children in the eastern half of the country to learn the Cyrillic alphabet first and the Roman alphabet second and for children in the western half of the country to learn the two alphabets in the reverse order. Typically, the first year and a half of schooling would be spent on the first alphabet and then children would master the other alphabet by the end of their second year. Today, the custom is continued only in the republics that remained part of Yugoslavia.

Learning an alphabet includes learning how to distinguish reliably among the letters as visual forms, learning that many different variants of a form are the same letter, and learning that the letters represent phonemes and not syllables or some other unit of the language. Presumably, once a child has learned one alphabet, learning the second alphabet is a far less daunting challenge. At the very minimum, the child faced with the second alphabet knows how to decode letters into phonemes.

Figure 1
Serbo-Croatian's Two Alphabets



Note. In the 1800s, the Serbian scholar Vuk Karadžić (1787–1864; shown above), and the Croatian scholars Ljudevit Gaj (1809–1872) and Ivan Broz (1852–1893), crafted a phonemically precise alphabet in two partially overlapping forms in order to bring uniformity to the transcription of the Serbo-Croatian language. Most of the letters of the Cyrillic and Roman variants of this new orthography were unique to either one or the other variant but some letters were shared. Seven of the shared uppercase letters were given the same phonemic interpretation in both alphabet forms (so-called *common* letters). This was not true of the remainder of the shared letters (so-called *ambiguous* letters). Their phonemic interpretation of Roman letters was different from their phonemic interpretation of Cyrillic letters. (Circled letters are used in the examples of words and nonwords shown in Figures 7 and 8.)



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This might suggest, therefore, that once the decoding processes are in place for the letters of the first-learned alphabet, aspects of these processes are borrowed and used to accommodate the second-learned alphabet. If so, then an asymmetry would exist between how the letters of the first-learned and second-learned alphabet are represented in memory. The representation of the second-learned alphabet would include, in some sense, the representation of the first-learned alphabet but not vice versa. Of course, it is possible that the two alphabets are learned independently, in which case the representations in memory of the letters of the two alphabets should not be affected by the order in which the alphabets were learned.

In the 1970s, we approached these issues through experiments in which adult skilled readers, living in Belgrade and fluent in both alphabets, were presented a randomized list of individual Roman and Cyrillic letters and given the task of simply answering for each letter the question "Is this letter Roman?" or the question "Is this letter Cyrillic?" (G. Lukatela, Savić, Ognjenović, & Turvey, 1978). They were encouraged to answer as quickly as possible, and we measured the latencies of their responses. Adults who had learned Cyrillic first as a child took longer to identify a letter common to the two alphabets as a Roman letter than as a Cyrillic letter and found it harder to classify a unique Roman letter as not Cyrillic than to classify a unique Cyrillic letter as not Roman. The exact opposite was true for adults who had learned Roman first as a child. They took longer to identify a letter common to the two alphabets as a Cyrillic letter than as a Roman letter and found it harder to classify a unique Cyrillic letter as not Roman than to classify a unique Roman letter as not Cyrillic. In sum, these mature readers, accustomed to using both alphabets daily, were biased in their explicit classification of letters toward the alphabet that they learned first.

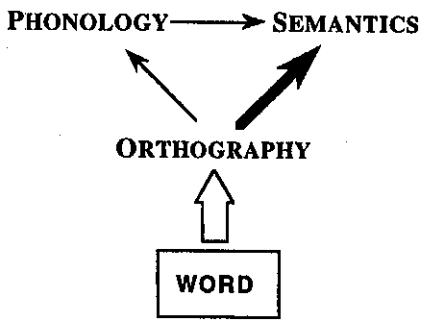
Another kind of experiment suggested that more subtle memory processes similarly reflect the order of learning. On a short-term memory test of the distractor variety (e.g., Peterson & Peterson, 1959), three consonant letters were read once, an arithmetic task was then performed for 10 seconds, and an attempt was then made to recall the three letters. Over four successive tests, using the same retention interval but different letter triplets and different versions of the distracting arithmetic task, recall accuracy declined dramatically. Typically, this decline is attributed to interference within short-term memory from the preceding letter triplets—so-called proactive inhibition or interference (Keppel & Underwood, 1962). A well-known phenomenon is that short-term recall recovers almost perfectly if, on the next succeeding test, the to-be-remembered material is drawn from a psychologically distinct class (Wickens, 1970); for example, personal pronouns rather than letters. In our experiment, bialphabetical Serbo-Croatian readers were switched on the fifth successive short-term memory test to uniquely Roman letters from uniquely Cyrillic letters or they were switched to uniquely Cyrillic letters from uniquely Roman letters. These readers had learned the Cyrillic alphabet first. Curiously, the "release" from proactive interference was found only for the switch in to-be-remembered material from Roman letters to Cyrillic letters (G. Lukatela, Savić, Ognjenović, et al., 1978).

We interpreted the preceding two sets of results in terms of Tversky's (1977) notion of asymmetric similarity. Similes and metaphors provide the typical examples. Thus, one might say that a highway is like a snake but one is much less likely to say that a snake is like a highway. As a general rule, the determination of subject and referent depends on the relative salience of the things involved, with the thing of greater salience assigned the status of referent. Then, the subject (the less salient thing) is deemed more similar to the referent (the more salient thing) than vice versa. With respect to the two successively learned alphabets, we argued that the first-learned alphabet assumes the role of referent. Accordingly, for a person who has learned Cyrillic first, processing Roman should seem more similar to processing Cyrillic than vice versa. Hence, in the release-from-proactive interference experiment, for example, release for these readers ought to occur less in the Cyrillic to Roman direction than in the Roman to Cyrillic direction. It proves to be the case, however, that despite the precedence of the first-learned alphabet, fluency in both alphabets renders the reader unwittingly prone to the unique problem cited above. To read a word like *potop* is to generate implicitly four phonological forms.

Ambiguous Words

The most influential theory of visual word recognition is the dual-route theory (Coltheart, 1978; see Figure 2). Assuming a storehouse of word representations (an inter-

Figure 2
Dual-Route Theory



Note. It is often hypothesized that a reader has two ways to go from the printed word to its meaning (semantics) in memory. One route, marked with the bold arrow, is direct and involves accessing the printed word's meaning on the basis of its orthographic interpretation (i.e., the letters and letter combinations that compose it). The other route, marked with the lighter arrow, is indirect and involves an intermediate step of converting the orthographic interpretation into a phonological interpretation through the use of rules. This second route is thought to be slower and less preferred by the skilled reader.

nal lexicon, a semantic memory), there are two paths to this storehouse from the internal site at which a viewed word's letter code is formed. One path goes directly to the storehouse (albeit via one or more recodings of the graphemic information). The other path is more involved, incorporating a transformation in the modality of the code. On this path, the letter or orthographic code is converted by rules to a phoneme code (that is, a code involving abstract representations of the sounds of speech), and then this phoneme code is used to access the storehouse. Of the two paths, the direct, nonphonological path will generally be faster.

The kinds of words that benefit most from the direct path are words with which the reader is familiar and words that do not obey the rules for translating letters into phonemes. When a word has been seen often in one's past, the direct connection between the word's letter code and its representation will be strong; when it has been seen rarely, the connection will be weak. A rare word, therefore, may travel to the storehouse as quickly by the indirect path as by the direct path. When a word does not obey the regular assignment of phonemes to letters (consider *have* in the light of *wave, save, cave,* and *rave*), its pronunciation cannot be determined by the rules of the indirect path but can be recovered from memory through the direct path. Clearly, the indirect path, with its embodiment of the alphabetic principle, is the better bet for pronouncing nonsense words such as the *slithy toves* of Lewis Carroll's poem "Jabberwocky." Novel letter strings that are not words do not have representations in the storehouse and, therefore, their pronunciations cannot be determined by the direct path.

The initial investigations of reading Serbo-Croatian words were conducted, by ourselves and our colleagues, in the framework of the dual-route theory. The common Serbo-Croatian word meaning *wind* (referring to air currents) is transcribed in upper case letters as BETAP in Cyrillic and VETAR in Roman. Casual observation suggests that a reader competent in the two alphabets reads this word as easily in the one alphabet as in the other. The conscious impression of such readers is that this is very much the case; reading *wind* transcribed as BETAP is no more mentally demanding than reading *wind* transcribed as VETAR.

Despite this apparent sameness, it could well be the case that a bialphabetic reader's unconscious mental processes are somewhat more complex when reading BETAP than when reading VETAR. One way to think about this additional complexity is in terms of ambiguous letter codes for *B* and *P*. It is fairly obvious that letter codes must be abstract. After all, a letter's identity is unchanged over wide variations in how it looks—variations, for example, of case, style, size, and orientation. Suppose each ambiguous letter has two abstract letter codes. Both codes would incorporate, in the same way, the distinctive visual components of the letter and the interrelationships that hold among these visual components. Where the codes differ, presumably, is in respect to an additional property that is not visual. Namely, one of the two codes would specify membership in the Cyrillic alphabet, whereas the other code would specify membership in the Roman alphabet. Implicitly, this distinction between the letter's codes represents the letter's different functional roles within the two alphabets. It would seem, therefore, that *B* and *P* are ambiguous in the mind of the bialphabetical reader, not because they have ambiguous visual representations, but because, in both cases, their corresponding letter codes (albeit abstract) specify two phonemes. Accordingly, a more appropriate way to think about the additional complexity of BETAP is that the letter–phoneme codes known by the bialphabetic reader lead to four different phoneme sequences—which can be written for simplicity as /vetar/, /betar/, /vetap/, /betap/—only one of which, /vetar/, corresponds to the word. Some amount of time might be needed, therefore, to settle the dispute among these codes in favor of the only one that is relevant. In contrast, the absence of ambiguous letters in VETAR means that the bialphabetic reader's letter–phoneme codes generate only one phoneme sequence, /vetar/.

Now, none of the preceding complications with respect to BETAP should matter very much if full knowledge about a frequent word is quickly retrievable from its optical form by the direct route of dual-route theory. If it is, then the lengths of time needed to determine that BETAP and VETAR are represented in the internal dictionary should be the same as should the lengths of time needed to begin pronouncing them. Our original experiments, however, did not find these expected temporal identities (Feldman, 1981; Feldman & Turvey, 1983; G. Lukatela, Savić, Gligorijević, Ognjenović, & Turvey, 1978; G. Lukatela, Popadić, Ognjenović, & Turvey,

1980). In both rapid lexical decision ("Is this string of letters a word?") and rapid naming ("How is this string of letters pronounced?"), strings of letters like BETAP were responded to more slowly than strings of letters like VETAR. These experimental outcomes would be expected if naming a word and finding its representation in one's internal dictionary depended in some way on resolving a unique phoneme sequence, a unique phonological code. If they do, then the time to name BETAP and the time to make a lexical decision should both be longer than the corresponding times for VETAR.

Our initial investigations, therefore, painted a very different picture of visual word processing than that based on the results of English language studies. The English results implied that the hallmark quality of reading maturity is the preferential use of the direct visual route; in contradiction, our results were suggesting a bias of mature Serbo-Croatian readers toward the indirect phonological route. This suggestion has been reinforced by the subsequent research that has studied the effect of phonological ambiguity in various contexts (Feldman, Kostić, Lukatela, & Turvey, 1983; G. Lukatela, Feldman, Turvey, Carello, & Katz, 1989; G. L. Lukatela, Carello, Peter, Lukatela, & Turvey, 1996; G. Lukatela & Turvey, 1987; G. Lukatela, Turvey, Feldman, Carello, & Katz, 1989) and as a function of word frequency (G. Lukatela, Lukatela, Carello, & Turvey, in press). It has also been reinforced by experiments using tasks other than rapid naming and lexical decision, specifically, identifying masked words (G. Lukatela, Turvey, & Todorović, 1991) and responding to the question "Does the word you see match the word you hear?" (Frost, Feldman, & Katz, 1990).

Ambiguous Nonwords and Related Matters

In English language studies of the 1970s, the conviction that mature readers rarely rely on the indirect route was founded primarily on the observation that, in the lexical-decision task, phonological manipulations affected "no" responses to nonwords but did not affect "yes" responses to words. For example, it was found that whereas nonwords such as *mave* were rejected as words more slowly than nonwords such as *fust,* exception words such as *have* were accepted as words equally as fast as regular words such as *must* (e.g., Coltheart, Besner, Jonasson, & Davelaar, 1979). Accordingly, investigators argued that the direct, nonphonological route was the route of choice for words and, therefore, the primary mental process in ordinary reading (in which nonwords are rarely encountered).

Returning to Serbo-Croatian, it is a simple enough matter to construct a nonword parallel of the BETAP versus VETAR comparison, for example, BEMAP versus VEMAR. In our experiments with many variants of this basic contrast and with equal numbers of Roman and Cyrillic letter strings assuming the ambiguous role, we found that rejecting the phonemically ambiguous BEMAP as a word took significantly longer than rejecting the phonemically unique VEMAR as a word (e.g., Feldman & Turvey, 1983; G. Lukatela et al., 1980; G. Lukatela, Carello, Savić, & Turvey, 1986). This finding was not surprising given the results in English and what we had found with Serbo-Croatian words. What was surprising was that phonemic ambiguity sometimes affected the processing of nonwords less than it affected the processing of words. The size of the disadvantage for the phonemically ambiguous nonword BEMAP relative to the phonemically unique nonword VEMAR was smaller than that for the phonemically ambiguous word BETAP relative to the phonemically unique word VETAR. As noted above, investigators of word recognition in English had concluded that use of the indirect route must be rare in ordinary word recognition because phonemic influences are pronounced for nonwords but not for words. Applying the same logic, the conclusion to be drawn from the Serbo-Croatian results had to be quite the opposite: Use of the indirect route must be routine given that phonemic influences are at least as great, if not greater, for words than nonwords.

Does this routine usage of the indirect route extend to beginning readers of Serbo-Croatian? An argument from dual-route theory is that beginners may well start out trying to read by the indirect route but they ought to shift to the direct route, and bypass the slower indirect route, as they become more familiar with the visual forms of words. By this argument, better beginning readers are those who access a word's name visually. We found that third- and fifth-grade pupils, like adults, named phonemically ambiguous letter strings, both words and nonwords, more slowly than phonemically unique letter strings (Feldman, Lukatela, & Turvey, 1985). We also found that those fifth-grade children who read better were slowed more dramatically by phonemic ambiguity. Our inference was that the better beginning readers of Serbo-Croatian were those children who were more skilled in using the indirect route. As an aside, these experiments with beginning readers spoke to the effect of order of alphabet acquisition on naming. Children in the third grade who had learned Cyrillic first tended to name ambiguous Roman words more slowly than ambiguous Cyrillic words (they were biased toward the coding of the first-learned alphabet). By the fifth grade, however, such children were equally slow in naming ambiguous Roman words and ambiguous Cyrillic words relative to their unambiguous counterparts.

Another kind of evidence for the indirect route identified and pursued in the 1970s was that visually processing a word ought to be prolonged by the number of speech-related constituents. Experiments with English were not especially favorable to this expectation. Whereas the numbers of syllables and phonemes influenced the latency in pronouncing words (e.g., Frederikson & Kroll, 1976) and the accuracy of identifying letters in words that were hard to see (e.g., Spoehr, 1978), they did not influence lexical decision (e.g., Frederikson &

Kroll, 1976). Given the opinion that lexical decision involves accessing the store of word memories used in ordinary reading, the latter failure suggested that such access was not achieved ordinarily by the indirect path (e.g., Henderson, 1982). In this light, a remarkable finding with Serbo-Croatian was that the greater the number of phonologically ambiguous letters in a word, the longer the time needed to achieve lexical decision relative to the time required to decide on the lexical status of phonologically unique words of the same length (e.g., Feldman & Turvey, 1983). Contrary to the English results, the Serbo-Croatian results showed that visual lexical decision (and naming; Feldman, 1981) involves a process attuned to the phonological composition of words as specified by their spellings—that is, a process that is phonologically analytic (Turvey, Feldman, & Lukatela, 1984).

Orthographic Depth

These contrasting findings of studies with Serbo-Croatian and English led investigators to the question of whether the differences could be due to the nature of the mapping between letters and sound, which is simpler and more regular in Serbo-Croatian than in English. An hypothesis was advanced that the orthographies of different languages might differ in the degree to which they bias the reader toward or away from the indirect route (Katz & Feldman, 1981; G. Lukatela et al., 1980; G. Lukatela & Turvey, 1980). Thus, the phonemically more precise Serbo-Croatian orthography might be expected to bias the reader to the indirect route more so than the English orthography. In turn, English orthography might be expected to bias the reader to the indirect route more so, for example, than the unpointed Hebrew orthography which omits vowels.

A major evaluation of this hypothesis used words that were of equivalent frequency in Serbo-Croatian, English, and Hebrew and looked for differences between naming speed and lexical decision speed for these words and their nonword controls (Frost, Katz, & Bentin, 1987). The participants were native speakers who were tested in their native countries. The specific idea was that the shallower the orthography (the fewer computational steps between graphemes and phonemes), the smaller should be the role played by the lexicon in the naming process compared with the role it plays in the lexical decision process. Naming can be performed mostly over the phonological route. Consequently, the difference between naming and lexical decision times should be largest for Serbo-Croatian and smallest for Hebrew, with English in between. The experimental results supported this prediction.

Related research with Serbo-Croatian and English used a task in which participants judged as "same" or "different" a spoken word and a printed word presented simultaneously, with or without degradation of one of the two words (Frost & Katz, 1989). Degradation affected response latency in both languages, but it did so four times more severely in English than in Serbo-Croatian. If the judgments were based on phonology, and if the assembling of phonology from print was based on stronger, simpler rules or connections for Serbo-Croatian than for English, then it is not surprising, perhaps, that degradation was more damaging in the case of English.

One other line of research is important to mention. In English (and, for that matter, other languages of the world), a word is named faster if preceded by an associated or a semantically related word. This fact is consistent with the notions that the lexicon is very much involved in naming English words and that any prior boosting of a word's representation in memory will hasten the accessing of that representation and the recovery of information about how the word is pronounced. When such priming of naming was first sought in Serbo-Croatian, the opinion was that it should be weak at best and nonexistent at worst—given the orthographic depth hypothesis. The experimental results tended to confirm this suspicion (Katz & Feldman, 1983; Frost et al., 1987).

It is the case, however, that not all of a Serbo-Croatian word's phonology is derivable from the mapping of graphemes to phonemes (Carello, Turvey, & Lukatela, 1992; Ognjenović et al., 1983). Knowing where to put the stress depends on word memory as does the determination of a single pronunciation for words like BETAP. Consonant with these implications of a lexical role, the majority of experiments have found that naming in Serbo-Croatian, like naming in English, benefits from a preceding associate (Carello, Lukatela, Peter, & Turvey, 1995; Carello, Lukatela, & Turvey, 1988, 1994; G. Lukatela, Turvey, et al., 1989). Of special importance to understanding the underlying mechanism is the observation that associative priming is greater for the naming of phonologically ambiguous words than for the naming of phonologically unique words (G. Lukatela, Feldman, et al., 1989, Experiment 6). It seems, therefore, that the preactivation of a target word's lexical representation aids pattern selection at the phonological level more for BETAP (which cannot resolve a unique pronunciation without lexical influence) than for VETAR (which can). Similar observations have been made—and similar conclusions about mechanism might, therefore, be drawn (Carello et al., 1995)—for associative priming of naming in languages that use two scripts that differ in phonemic precision; specifically, Persian with its transparent and opaque scripts (Baluch & Besner, 1991) and Hebrew with its pointed and unpointed scripts (Frost, 1994).

Inflexible Processing

Although one's general language-processing abilities seem to operate automatically, a view common to many cognitive scientists is that the abilities are docile. That is, one can (unconsciously) adjust these abilities, within reasonable limits, to the situation. From the viewpoint of the dual-route theory, it can be assumed that the reading mechanism possesses a special type of flexibility, namely, if a route impedes reading, simply disable it. Accordingly, given that the indirect, phonological-mediation route is

presumed to slow the reading of words such as BETAP and to induce errors, the wise strategy in an experiment with many such words would be to close that route down and restrict all word processing to the direct, visual route. On the direct route, the letter sequence BETAP would be recognized as the word meaning *wind* quite straightforwardly, without any interference. Similarly, for a bialphabetic reader, this assumed flexibility can be expected to extend to the alphabet codes: If the Roman alphabet code interferes with reading a Cyrillic word (e.g., BETAP), or vice versa, then disable it.

This conjectured flexibility can be examined by presenting words written in only one alphabet (meaning that there are no letters unique to the other alphabet, see Figure 1). In such a situation, an ability to ignore the other alphabet code would mean that any uppercase word that includes the letters *H, P, C,* or *B* would be processed with comparable speed and accuracy to an uppercase word that did not include such letters. We addressed this issue in a lexical decision experiment using only words and nonwords transcribed in the Roman alphabet (G. Lukatela, Savić, Gligorijević, et al., 1978). That is to say, no uniquely Cyrillic letters ever appeared. Of the words used in the experiment, only 9% were phonologically ambiguous, and these were readable as words only with the Roman alphabet code. Despite these efforts to make the Cyrillic alphabet irrelevant and to encourage its suppression, decision times were slowed by the presence of letters that received one phonemic interpretation in Roman and another, different interpretation in Cyrillic.

If the Roman and Cyrillic codes cannot be disabled individually, as the preceding result suggests, then perhaps they can be disabled together by simply biasing the reader to the visual, direct route. With respect to the conducting of experiments in English, a frequent argument has been that presenting the participant with a large number of words and nonwords with irregular pronunciations, or nonwords that sound like words, will prolong the average lexical decision time if the reader were to rely at all on the indirect route. The argument leads to the surmise that shutting the indirect route down and limiting processing to the direct route would protect the reader from the punishing effects of letter strings that are hard to code phonologically and of nonwords that falsely excite word representations through a common phoneme sequence. In some of our experiments with Serbo-Croatian, 50% of the letter strings seen by a participant were phonologically ambiguous (G. Lukatela, Feldman, et al., 1989). The sensible strategy for the participant faced by so much ambiguity arising from the use of the letter-to-phoneme mappings of the Roman and Cyrillic alphabets would be to disable the indirect route. The experimental results showed, however, that the effect of phonological ambiguity persisted; responses to stimuli like BETAP remained substantially slower than responses to stimuli like VETAR.

A closely related argument in the literature focuses on the associative priming of naming rather than naming itself. The argument begins by recognizing that associations among words are represented in the internal lexicon and that associative priming, therefore, can only occur through activation of the lexicon. It then notes that because the lexicon is typically accessed by the direct route, and because pronunciations are stored there, naming a word will typically benefit from the prior presentation of one of its associates. The only way associative priming of naming can be thwarted is by deriving a word's pronunciation strictly over the indirect route, without involvement of the lexicon.

Some experimental circumstances are thought to bias the reader toward the indirect route; most notably, the presence of a large number of nonwords among the letter strings that are to be named. Because nonwords can only be named over the indirect, phonologically mediated route, the reader in the experiment is thereby encouraged to use that route for naming the word stimuli as well (e.g., Tabossi & Laghi, 1992). So the question can be raised: Is the lexical influence on the fluent naming of Serbo-Croatian words flexible in the sense that associative priming occurs or not depending on how much the circumstances encourage the indirect route? The answer seems to be no. We conducted experiments that compared the same word prime–word target pairs in the presence of, or in the absence of, an equal number of word prime–nonword target pairs (Carello et al., 1995). All letter strings in these experiments were phonologically unique and had regular stress patterns. The associative priming of naming in both conditions was reliable and of equivalent magnitude.

Among the possible interpretations of the preceding finding, the one that stands out is that which ascribes the processing of words and nonwords to one and the same mechanism. This interpretation is far from trivial. It goes against the dual-route model and the conceptual basis for the orthographic depth hypothesis. An alternative to the view of visual word recognition expressed in Figure 2 is implied. It could be provided by the currently popular idea, originating with McClelland and Rumelhart (1981), of the reading mechanism as a network of weighted connections among layers of processing units (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). This idea flourishes with demonstrations that an alphabet can indeed be disabled, but only briefly, and then in degrees.

Alphabet Biasing

There is another experimental procedure by which one might try to thwart the phonological ambiguity that arises from the different phonemic encodings of the same letter shapes. Instead of tempting the fluent bialphabetical reader to forego one of the alphabet codings by manipulating the proportion of this or that kind of item seen over the course of the experiment, one can try to introduce a temporary bias toward the Cyrillic interpretation of, say, BETAP by means of a preceding letter string that is composed of only uniquely Cyrillic letters.

The idea is that if the reader sees BETAP soon after seeing a letter string (either a real word or non-word) that engages just the Cyrillic alphabet code, then—for just a moment—the reader might be strongly biased to code *B* as /v/ and *P* as /r/. We found evidence for this conjecture of an "alphabet-biasing" effect in the sense that the time needed to start pronouncing BETAP-type words, or to decide on their lexical status, was reduced dramatically when preceded by phonologically unique letter strings in the same alphabet relative to phonologically unique letter strings in the other alphabet (G. Lukatela, Turvey, et al., 1989).

Five features of this forward alphabet biasing suggest the nature of the underlying mechanism. First, it can be induced by nonwords as well as words, and it can be induced (to lesser degree) by a single letter (G. Lukatela et al., 1991). Second, it can be induced by words, nonwords, and single letters rendered minimally visible by masking (G. Lukatela et al., 1991). Third, it is absent in the case of phonologically unambiguous VETAR-type words (they are responded to no faster when preceded by phonologically unique letter strings in the same alphabet than when preceded by phonologically unique letter strings in the other alphabet; G. Lukatela, Turvey, et al., 1989). Fourth, it is complete for a lag of one tenth of a second between the alphabet prime and the phonologically ambiguous word and declines as the lag time increases to approximate the no-bias condition within one and a half seconds (G. Lukatela, Lukatela, Carello, & Turvey, 1993). And, fifth, it is less for phonologically ambiguous target words degraded by visual noise than for phonologically ambiguous target words that are visually intact (G. Lukatela et al., 1993).

There would seem to be two major implications of the preceding five results. We described above how it is that a global alphabet bias (all words or nonwords in the experiment were composed from the letters of just one alphabet) is ineffective. Despite the obvious restriction to stimuli in one alphabet, and the readers' conscious appreciation of the restriction, it proved impossible for the readers to turn off the coding routines of the other alphabet. (In that experiment, by the way, the lag time between stimuli was about one second.) In contrast, the immediately prior presentation of a phonologically unique nonsensical letter string that was unidentifiable (due to masking) did the trick, suggesting that low-level automatic mechanisms can restrict letter coding to one set of rules but high-level conscious, strategic mechanisms cannot. In Pylyshyn's (1984) phrase, the mechanism responsible for alphabet biasing is cognitively impenetrable. The other major implication is that extensive experience with the Serbo-Croatian alphabets has produced a network of connections between letters and phonemes within which the two alphabets are functionally separate but interactive.

Our efforts (G. Lukatela et al., 1991, 1993) to capture this latter implication are depicted in Figure 3. Experience, it seems, has endowed the bialphabetical reader with a special-purpose mechanism for circumventing letter–phoneme ambiguity. This mechanism reduces the effect of ambiguity when a unique letter is present in an otherwise ambiguous word, such as the П in ВЕПАР (see Figure 3). It can similarly reduce the effect of ambiguity on the processing of words that do not contain unique letters (such as BETAP) because it is tailored to the time scale at which the reader typically encounters successive words on an ordinary page of print where words usually appear in just one alphabet. Figure 4 depicts a rather compelling demonstration of the early automatic nature of this mechanism, one that entails an alphabet-specific context following rather than preceding a target word.

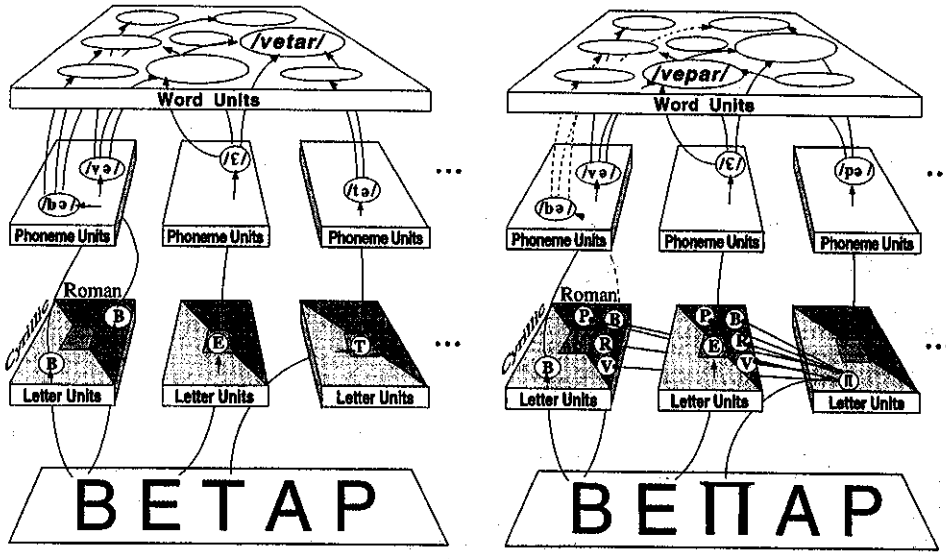
Virtual Words

The upshot of these investigations into a very short-lived alphabet bias is a better appreciation for how bialphabetical readers of Serbo-Croatian have met their unique challenge. They appear to have developed a processing mechanism with a microstructure which, in the first place, conforms to the tight covariation of letters and phonemes within the written language and, in the second place, interconnects in ways that are responsive to the competition created by the shared letters with different phonemic interpretations. The adaptation of these bialphabetical readers highlights the need to consider more generally and more broadly the specializations of the brain's reading mechanisms for the varied orthographies that transcribe the world's languages. The dimension of orthographic depth is not sufficiently encompassing (Katz & Frost, 1992; Seidenberg, 1992).

The story told thus far about the "front end" of the Serbo-Croatian reading mechanism is incomplete, however, in an important respect. The processes selecting a pattern of phoneme activity originate from above as well as from below. Our experiments on short-term alphabetic biasing revealed this interplay of higher and lower influences in a somewhat dramatic fashion through a class of nonwords that might be called *virtual words*. For example, the letter string POBOT composed only of the shared letters (see Figure 1) does not fit visually with any word in the Serbo-Croatian language but it does support four different pronunciations, one of which corresponds to the word pronounced /robot/ meaning *robot*. This word comes about by reading *P* as a Cyrillic letter and *B* as a Roman letter.

Suppose POBOT is preceded by AUTOMAT (a phonologically unambiguous word meaning *automaton*). Because AUTOMAT is patently Roman (see Figure 1), alphabet biasing should limit the reader to assigning the nonword phonemic sequence /pobot/ to POBOT. But because AUTOMAT is an associate of the word pronounced /robot/, it could, to the contrary, prime the reader for the word interpretation of POBOT. In both the lexical decision and naming tasks we found that, relative to a nonassociated alphabet prime, AUTOMAT significantly increased the tendency of participants to read POBOT as the word meaning *robot* (G. Lukatela, Turvey, et al., 1989;

Figure 3
A Mechanism for Alphabet Biasing



Note. For the processing of a single-letter position, each ambiguous letter is represented twice (once in the Cyrillic set and once in the Roman set), and each letter connects to its corresponding phoneme with no duplication of phonemes. This organization of connections repeats for each letter position of a visually presented letter string in the manner suggested by McClelland and Rumelhart (1981). The key idea is that, across letter positions, there are multiple inhibitory connections in both directions between the unique letter-processing units of one alphabet and the unique and ambiguous letter-processing units of the other alphabet (left). Consider BETAP with its shared unambiguous letters *E, T,* and *A* and its ambiguous letters *B, P.* The letter *B* in the first position will excite strongly /və/ and /bə/ and raise significantly the activation of all word units with these initial phonemes. The fully unambiguous VETAR (not shown), has two unique letters that will inhibit all Cyrillic alphabet units in other positions and *V* in the first position will activate only /və/ and only word units beginning with /və/. With a little elaboration, one begins to see that it will take longer to distill out a single, dominant word unit in the case of BETAP than VETAR (right). The word BEПAP (meaning boar) is an interesting case with two ambiguous letters (*B, P*), two shared unambiguous letters (*E, A*), and one unique letter (П). Because of the inhibition induced by П, the time to resolve a single, dominant word unit in the case of BEПAP will be faster than that needed in the case of BETAP (Feldman et al., 1983). In general terms, the greater the number of unique letter-processing units activated (at different positions), the greater is the resultant inhibition of the other alphabet. Within a matter of seconds, however, activation subsides and inhibition dissipates. To keep the schematic simple, the top-down flow of activation is not depicted. Experiments show that this downward influence can dilute the effects of inhibition at the letter level.

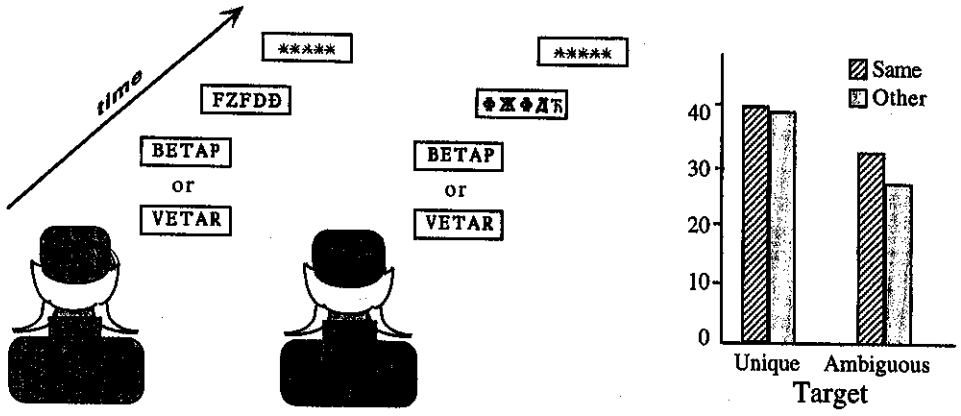
Experiments 4 and 5). That is, the bottom-up alphabet biasing of activity within the specialized letter-to-phoneme connections is not final. It can be modulated, and even overridden, by a downward flow of influence from the functional layer of lexical units.

Phonological Priming

In contrast to the major lesson taught to students of reading by the dual-route theory, the major lesson of the Serbo-Croatian research summarized thus far is that the processing level at which phonological representations emerge is pivotal to reading words. The convergence of influences at this functional level and the time it takes them to form a unique phonological code seem to be the key factors in the fluent identification of words by eye. The preceding impressions are sharpened by the results of experiments in which one word's phonology affects the rate of identification of a following word with similar phonology.

In Serbo-Croatian, two words with a great deal in common phonemically can look very different visually. This is because they can be written in different alphabets and in different cases. For example, the visually dissimilar, semantically unrelated pair putić–ПУЖИЋ (meaning *lane* and *snail,* respectively) differ only in the middle phoneme. The special experimental advantage of being able to create such visual dissimilarities between similar sounding but semantically unrelated words is that one can use different variants of the same word pairs to evaluate whether a word can influence another purely on phonemic grounds. Thus, visually dissimilar forms of the word pair *lane–snail* such as putić–ПУЖИЋ and ПУТИЋ–PUŽIĆ can be compared with visually similar forms of the same word pair such as путић–ПУЖИЋ, putić–PUŽIĆ, ПУТИЋ–ПУЖИЋ, and PUTIĆ–PUŽIĆ. When readers skilled in both alphabets are asked to name or to determine the lexical status of the second member of a pair presented in close succession (a lag of about one half of a second), their response times are influenced by phonemic similarity but not by visual similarity (G. Lukatela & Turvey, 1990b). Only the likeness in sound matters; the visual likeness proves to be irrelevant. This result, like many of the others described above, indicates that the mature reading of Serbo-Croatian is anchored in

Figure 4
Retroactive Alphabet Biasing



Note. Alphabet biasing can be achieved with an alphabet-specific nonword that follows rather than precedes a target word (G. Lukatela et al., 1991; Experiment 5). The idea is that given two masks, one that shares particular features with a preceding target word and one that does not, the former can provide some compensation for the interruption of processing by continuing the activation of the processing units activated by the target (e.g., G. Lukatela & Turvey, 1990b; Perfetti, Bell, & Delaney, 1988). The figure shows an observer (Karadžić himself!) viewing a target word (40 milliseconds) followed by a string of consonants (40 milliseconds) that specifies either one or the other alphabet followed, in turn, by an overlapping pattern mask. BETAP will activate /b/, /v/, /e/, /t/, /a/, /p/, and /r/. The following Roman mask FZFDĐ will terminate the processing of BETAP and, given the inhibitory connections shown in Figure 3, suppress the activity of the phoneme processing units corresponding to /v/ and /r/ representing the Cyrillic interpretations of *B* and *P*. The upshot is that the Roman mask will reduce further the likelihood of BETAP activating the word pronounced /vetar/. With respect to the following Cyrillic mask ФЖФДЂ, it will terminate the processing of BETAP and, given the inhibitory connections shown in Figure 3, suppress the phoneme processing units /b/ and /p/ representing the Roman interpretations of *B* and *P*. That is, it will increase the likelihood of BETAP activating the word pronounced /vetar/. The bar graph summarizes the results. Same-alphabet masks led to significantly greater accuracy than other-alphabet masks, with the difference between the masks present for the ambiguous targets (BETAP) but not for the unique targets (VETAR).

speech-related processes rather than processes related to the visual forms of words. In terms of the dual-route theory, the traffic is mainly on the indirect route.

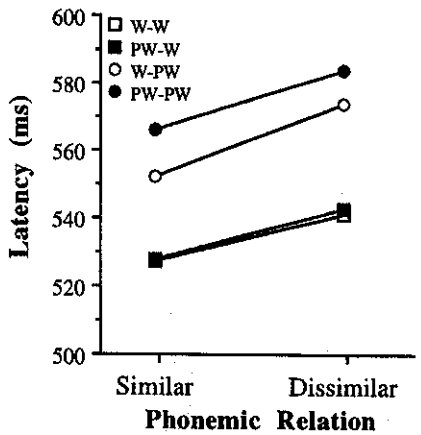
It is conceptually useful to consider, in the light of Figure 3, how a name is fashioned for ПУЖИЂ in the context of an immediately preceding, phonemically similar letter string. If the prime is a visually dissimilar word differing in only the middle phoneme (e.g., PUTIĆ), then it would activate the first and second, and the fourth and fifth, of ПУЖИЂ's five phonemes. Additionally, the prime would activate its own word representation in memory, and this lexical activity would, in turn, reinforce the excited phonemes by a top-down flow of activation. Thus, when ПУЖИЂ is presented, the details of its utterance—with the exception of the middle phoneme—have been well prepared in advance for transfer to the speech articulators. The scenario would be only slightly different, however, if the phonemically similar but visually dissimilar prime were a nonword. In this case, there would be no fully excited representation in word memory but there would still be a lot of lexical activity (the word representations that share the nonword's phonemes in the same positions) to feed to the phoneme level. Interestingly, almost the same scenario would occur if the letter string being primed was not ПУЖИЂ but a nonword with the same four phonemes in common with the prime.

To cut a long story short, the naming of words and the naming of nonwords should be affected to the same degree by the phonemic similarity of preceding letter strings regardless of whether those letter strings are words or nonwords. The experimentally observed pattern of pronunciation latencies agreed with our expectations. As can be seen in Figure 5, the influences of phonemic similarity and lexicality of primes and targets are simply additive (G. Lukatela, Carello, & Turvey, 1990). Such results encourage the view that the naming of Serbo-Croatian letter strings is based on the states of phoneme-processing units. In a hierarchical processing scheme such as that depicted in Figure 3, these states reflect the summed excitations arising from active letter units below and active word units above.

Mixing Alphabets

At some point, early promoters of Serbo-Croatian's two alphabets, might have wondered (fearfully, perhaps) whether readers would conflate the two scripts—that is, would they write words in phonologically correct mixtures of unique Cyrillic and unique Roman letters? For example, the word for *robot* might be written mistakenly as the nonword ROБOT, where the first letter is Roman and the middle letter is Cyrillic (see Figure 1). Such hybrid misspellings are not common in printed materials and are certainly not a common feature of everyday reading experience. The ultimate significance of these mixed-alphabet virtual words is scientific: They prove to be uncommonly useful tools for probing the mechanisms of visual word identification.

Figure 5
Phonological Priming of Naming



Note. Words (W) and pseudowords (PW) are used to prime the naming of other phonemically similar or dissimilar words and pseudowords. The effect of phonemic similarity (the advantage of similar over dissimilar) is the same regardless of the composition of the prime–target sequence.

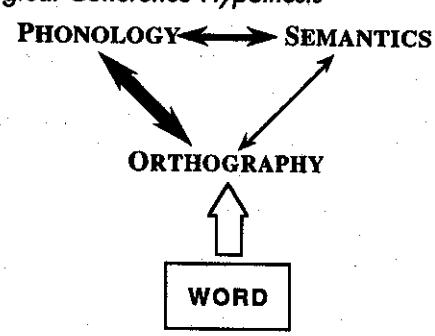
An important idea discussed earlier was that the time required to produce an unambiguous phonological code for a letter string may set the lower limit on the time it takes to name the letter string or to decide on its lexical status. This idea is closely similar to the phonological coherence hypothesis proposed by Guy Van Orden and his colleagues (Van Orden & Goldinger, 1994; Van Orden, Pennington, & Stone, 1990) depicted in Figure 6. It leads to some particularly novel, nonintuitive, and correct predictions.

Consider, for example, what transpires when a phonologically ambiguous word is used as a prime for itself; for example, ROBOT as a prime for ROBOT. If the time to process ROBOT the prime is severely restricted, there is a good possibility that its phonology will not have become coherent—that is, uniquely resolved ("is it /rovot/ or /robot/?")—prior to the appearance of ROBOT the target (that is, the stimulus to be named or lexically evaluated). If such is the case, then the phonological coherence hypothesis predicts that the reader's processing of ROBOT the target should not benefit much from the reader's earlier processing of ROBOT the prime. That is to say, despite the graphemic, semantic, and syntactic sameness of the prime and target, failure to resolve the phonology of ROBOT as prime should compromise this word's ability to prime itself. Under the very same restrictive conditions, however, the hypothesis predicts that the phonologically unique nonword ROБOT (which, in combining both unique Roman and unique Cyrillic letters, permits only the phoneme sequence /robot/) could very well be an effective prime for ROBOT. Within the limited processing time, ROБOT—even though it is both a novel and illegal spelling for readers—would give rise to a coherent phonological code. What is startling about all of this is the realization that a word need not necessarily be its own best prime; in theory, a never-seen-before nonword could prime a word better than the word itself!

In our experiments testing this peculiar prediction, we used, of course, many variants of the type of contrast typified by ROBOT and ROБOT in both predominantly Cyrillic and predominantly Roman forms. On each trial, we separated the onsets of prime (always in uppercase) and target (always in lowercase) by either 70 milliseconds or 250 milliseconds, preceded the prime by a long-duration mask, and inserted another mask of much shorter duration between the prime and target (G. Lukatela, Savić, Urošević, & Turvey, 1997). The combination of the masks with the very short delay between prime and target onsets was used to severely limit the processing of the prime. In agreement with expectations, we found that at the shorter interval between onsets but not at the longer, ROБOT primed ROBOT better than ROBOT primed ROBOT in both the naming and lexical decision tasks (see Figure 7).

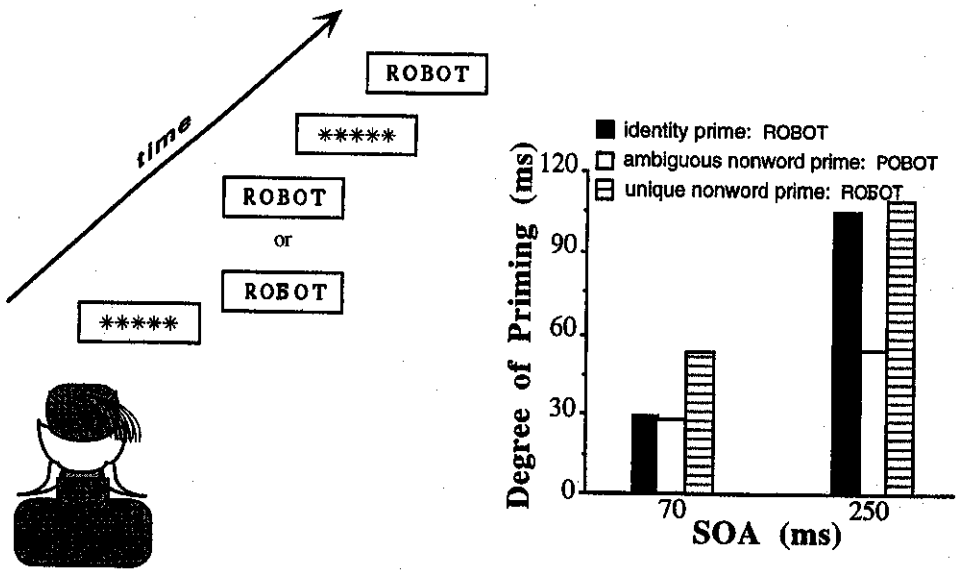
One can take the phonological coherence hypothesis a step further. AUTOMAT is an associate of ROBOT. This means, roughly speaking, that within a person's memory there is a connection from *robot* to *automaton*. The hypothesis suggests that, with limitations on prime processing time, ROБOT ought to be a better associative prime for AUTOMAT than the proper associate ROBOT. Once again the

Figure 6
Phonological Coherence Hypothesis



Note. In contrast to the proposal from dual-route theory, phonology may provide the earliest constraint on visual word recognition. The schematic depicts the ideas advanced by Guy Van Orden and his colleagues (Van Orden et al., 1990). Activation from the visual analysis of a presented word spreads to three different kinds of linguistic features defining three interconnected subsystems—orthographic, phonological, and semantic. The time course of achieving a fit or coherence between the active features of any two subsystems depends on how systematic is the mapping between them. It is argued that the most systematic mapping is that between orthography and phonology and the least systematic mapping is that between orthography and semantics. The differences in boldness of the double arrows linking the subsystems reflect the differences in the degrees to which the mappings are systematic. Because of its faster rate of coherence, the orthographic–phonological activity serves to mediate the coherence and stability of the system as a whole. A key idea with experimental consequences is that the lower limit on orthographic–phonological time-to-coherence sets the lower limit on word recognition time.

Figure 7
Identity Priming



Note. Here, Karadžić is viewing a rapid succession of four stimuli: a mask (500 milliseconds), a prime (35 milliseconds), a mask (35 milliseconds), and a target (400 milliseconds). The time between the onsets of the prime and the target, the stimulus onset asynchrony (SOA), is either 70 milliseconds or 250 milliseconds. In an experiment reproducing these presentation conditions, the nonword ROBOT produced by mixing the alphabets was a better prime for a lexical decision on ROBOT at the shorter SOA than ROBOT itself (G. Lukatela et al., 1997). According to the phonological coherence hypothesis, this is because ROBOT has only one phonological code and, therefore, achieves coherence sooner than ROBOT, which has two phonological codes. (POBOT, by the way, has four phonological codes.)

key ideas are that word representations in memory are activated by phonological codes and that, in any given instance, the lower limit on access time is set by the time needed to form such a code. For fixed and brief conditions of presentation, if *robot* can be accessed sooner by ROBOT than by ROBOT, then it will be the case that *robot*'s associate *automaton* will be coactivated longer and, therefore, more strongly, by ROBOT than by ROBOT.

In agreement with expectations, our experiments showed (see Figure 8) that, under time limitations, nonsensical and previously unseen letter strings such as ROBOT activate associative memory better than highly familiar real-word associates such as ROBOT (G. Lukatela, Carello, Savić, Urošević, & Turvey, in press). Karadžić, Gaj, and Broz could never have imagined that their alphabet reforms would be so revealing of the human mind.

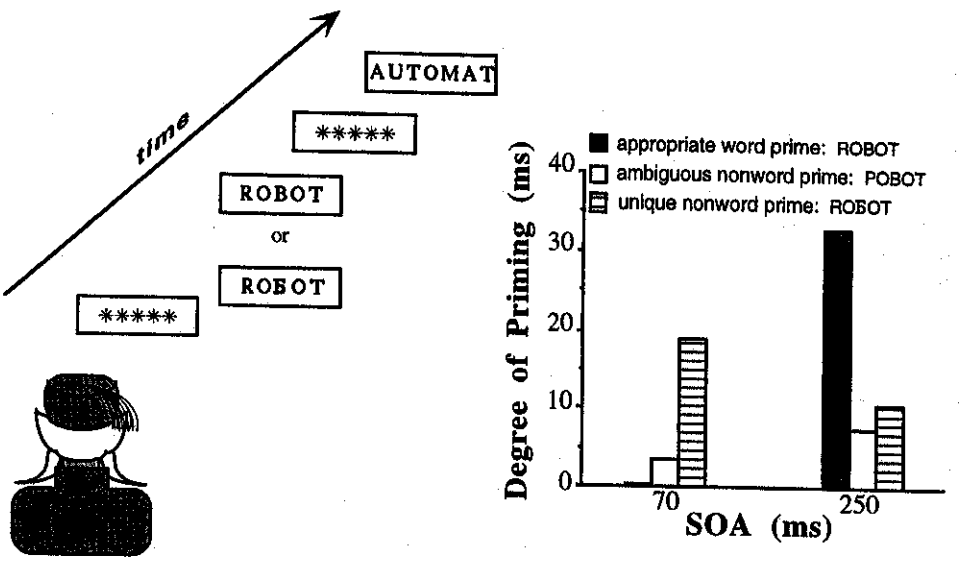
Phonological Awareness and the Alphabetic Principle

The issue of whether reading is primarily a visual or linguistic skill has been debated fiercely for more than a century (Huey, 1908/1968). The great virtue of dual-route theory, or so it seemed, was the elegant resolution of the debate in favor of both opinions. Reading's labor was divided between the two kinds of skill according to circumstance and degree of literacy. It was seen as an uneven division, however, with the visual side assuming the larger responsibility. Despite several major changes in the theory—to accommodate many of the new facts gathered since its inception—the uneven division favoring the visual route remains (Coltheart, Curtis, Atkins, & Haller, 1993).

Although we had presumed the appropriateness of the dual account when we began our investigations, evidence for visual constraints on the pronouncing and recognizing of printed Serbo-Croatian words failed to materialize. A similar lack of direct evidence for the visual route in the reading of individual English words has recently been highlighted. Typically, use of the visual route has been inferred from negative evidence for a phonological influence (e.g., Ehri, 1992; Van Orden et al., 1990). The few studies seeking direct evidence for its leading role have not been favorable. Extensive learning of arbitrary spellings (lacking letter–sound relations) and systematic spellings should have the same consequences if the primary process is a mapping of visual forms onto word memories. The results are to the contrary. People highly practiced in reading words spelled either arbitrarily or systematically (that is, phonologically) are better at reading the latter (e.g., Brooks, 1977; Spring, 1978).

The historical difficulty of satisfying the proposed criteria for phonological mediation in English language studies contrasts sharply with the ease with which these criteria have been met in the experiments with Serbo-

Figure 8
Associative Priming



Note. Karadžić is again shown viewing a rapid succession of four stimuli as in Figure 7. This time, however, the target is an associate of the word prime. In an experiment reproducing these presentation conditions, the nonword ROBOT produced by mixing the alphabets was a better prime for a lexical decision on AUTOMAT at the shorter stimulus onset asynchrony (SOA) than ROBOT itself (G. Lukatela, Carello, et al., in press). According to the phonological coherence hypothesis, this finding occurs because ROBOT has only one phonological code and, therefore, achieves coherence and activation of word memory sooner than ROBOT which has two phonological codes. POBOT must take even longer because it has four phonological codes. The facts that the effectiveness of ROBOT as an associative prime declines with an increase in SOA, and POBOT never attains such status, suggest contributions from orthographic constraints whose clean-up role becomes apparent only after phonological constraints have set the stage.

Croatian. Initially, we attributed the difference to the fact that Serbo-Croatian orthography was shallow relative to the English orthography and, therefore, induced a more obvious bias in the Serbo-Croatian reader toward using the indirect phonological route (G. Lukatela et al., 1980). We no longer believe that the difference is one of whether or not phonology is routinely involved in visual recognition of English and Serbo-Croatian words. We now think that the difference is merely methodological, a matter of the greater simplicity with which one can contrive an experimental demonstration of phonological involvement in Serbo-Croatian than in English (Carello et al., 1992; G. Lukatela & Turvey, 1994a). The legacy of Karadžić, Gaj, and Broz, from a scientific perspective, was an off-the-shelf method for constructing letter strings in Serbo-Croatian in which meaning, syntax, frequency, associations, and so on could be controlled experimentally while distinguishing orthographic from phonological similarity. For other writing systems such controls must be invented in conjunction with clever procedures that permit the precise manipulation of phonology—a charge that is demanding but not impossible. Encouraging responses to the charge include the research of Bosman and de Groot (1996) in Dutch; Grainger and Ferrand (1996) in French; Frost (1995) in Hebrew; Perfetti, Zhang, and Berent (1992) in Chinese; Sebastián-Gallés (1991) in Spanish; and Van Orden (1987), G. Lukatela and Turvey (1994a, 1994b), and G. Lukatela, Frost and Turvey (in press) in English.

The upshot of the preceding is that the evidence for phonology's leading role in reading individual Serbo-Croatian words should be viewed as general (applying to all alphabetic orthographies) rather than special (applying to just those that transcribe a minor Slavic language). This view is consonant with two basic facts: First, phonological structures are the universal basic materials for the normal syntactic processes at work in speech comprehension and, second, these phonologically centered processes are well in place by the time the less natural skill of reading begins to be acquired. Accordingly, as Alvin Liberman (1991) remarked

> 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. (pp. 242–243)

The aforementioned "seemingly sensible strategy" is not a strategy that is easily taken, however, and the very nature of this difficulty bespeaks phonology's central role. Using the seemingly sensible strategy presupposes an awareness that spoken words break apart into phonological segments, an awareness that is opposed by

the very nature of speech. In spoken words, phonemes overlap greatly and do not correspond to discrete, identifiable sounds; furthermore, listening to speech delivers a conscious awareness of words but on the back of an unconscious registration of the phoneme sequences that compose them. A would-be-reader of any alphabetic script is challenged, therefore, by the task of making the phonology of spoken words explicit, for only by so doing can he or she take advantage of the alphabetic principle (e.g., I. Y. Liberman, Shankweiler, & Liberman, 1989). This principle is not that letters represent speech sounds but rather that they represent the more remote phonological (and morphophonological) segments conveyed by speech sounds. As often remarked, the spoken English word *bag* consists not of one segment but of three segments (differing from *sag* in the first, *big* in the second, and *bat* in the third) that happen to be opaque in the surface sound and transparent only in the underlying phonology. A common finding in many languages (including Serbo-Croatian; K. Lukatela, Carello, Shankweiler, & Liberman, 1995) is that, despite the adequacy of their speech, preliterate children and adults are not necessarily aware that words have internal phonological structure (Brady & Shankweiler, 1991). They are, therefore, unable to use the alphabetic principle because this internal phonological structure, unknown to them explicitly, is the very structure that an alphabet represents. In line with the preceding, the best single predictor of reading success proves to be the degree of phoneme awareness (Adams, 1990; Brady & Shankweiler, 1991).

Unraveling the Tangled Story

Although Serbo-Croatian is not included among the world's most used and studied languages, it has provided, in our view, the most compelling evidence to date that skilled reading is fundamentally a phonologically analytic process. The research on written Serbo-Croatian in its Cyrillic and Roman forms has strengthened and clarified the growing understanding that reading success and reading failure are intimately tied to the brain mechanisms that conduct phonological processes. One suspects that Vuk Karadžić, Ljudevit Gaj, and Ivan Broz would have been pleasantly surprised to know that their parochial efforts to provide a uniform transcription of Serbo-Croatian have contributed to the understanding of a universal human condition. The scientific significance of that understanding cannot be underestimated, as Edmund Burke Huey (1908/1968) expressed so eloquently 90 years ago:

> And so to completely analyze what we do when we read would almost be the acme of a psychologist's achievements, for it would be to describe very many of the most intricate workings of the human mind, as well as to unravel the tangled story of the most specific performance that civilization has learned in all its history. (p. 6)

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