

# Phonological Ambiguity and Lexical Ambiguity: Effects on Visual and Auditory Word Recognition

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Three experiments in Serbo-Croatian were conducted on the effects of phonological ambiguity and lexical ambiguity on printed word recognition. Subjects decided rapidly if a printed and a spoken word matched or not. Printed words were either phonologically ambiguous (two possible pronunciations) or unambiguous. If phonologically ambiguous, either both pronunciations were real words or only one was, the other being a nonword. Spoken words were necessarily unambiguous. Half the spoken words were auditorily degraded. In addition, the relative onsets of speech and print were varied. Speed of matching print to speech was slowed by phonological ambiguity, and the effect was amplified when the stimulus was also lexically ambiguous. Auditory degradation did not interact with print ambiguity, suggesting that perception of the spoken word was independent of the printed word.

In the past decade, the problem of lexical ambiguity has attracted the attention of many researchers concerned with models of printed word recognition. Because lexical ambiguity exists in many languages, an examination of the process of disambiguation may clarify the relation between orthography and phonology in the mental lexicon.

Ambiguity can exist in the relations between the orthographic and phonological forms of a word or between the phonological form and its semantic representation. The printed word *bank*, for example, has one pronunciation (and therefore an unambiguous phonological representation) but two meanings. In contrast to *bank*, the printed word *wind* has two different phonological representations (/wind/ and /waynd/), each of which has a different semantic meaning. If we consider a word to be, first of all, a phonological structure and the word's phonological representation to be its lexical entry, then the printed form *wind* has two lexical entries, each of which is semantically differentiated. Resolving the phonological ambiguity necessarily designates one specific lexical entry, which, in turn, automatically disambiguates the semantic representation (and vice versa). The top of Figure 1 diagrams these relations for English.

Effects of semantic ambiguity on visual word recognition have been demonstrated in several studies (for a review see Simpson, 1984). Rubenstein, Lewis, and Rubenstein (1971) showed that lexical decisions are faster for homographs like

*bank* than for nonhomographic words. The explanation for this effect was that words with multiple meanings have multiple lexical entries, and therefore the probability of encountering one of them is greater than the probability of detecting a single entry (see also Jastrebnsky, 1981). Effects of phonological ambiguity were demonstrated in the naming task, which, by its nature, requires a fully specified phonological form. Homographs like *wind*, which are phonologically ambiguous, take longer to name than homographs with a single pronunciation (Kroll & Schweickert, 1978).

An additional source of phonological ambiguity can be demonstrated in languages with two distinct and equivalent orthographies like Serbo-Croatian. In Serbo-Croatian, the Roman and the Cyrillic alphabets are both taught to all elementary school children and are used interchangeably by the skilled reader. Most characters in the two alphabets are unique to one alphabet or the other, but there are some characters that occur in both. Of those, some receive the same phonemic interpretation regardless of alphabet (*common* letters), but others receive a different interpretation in each alphabet (*ambiguous* letters). Letter strings that include unique letters can be pronounced in only one alphabet. Similarly, letter strings composed exclusively of common letters can be pronounced in the same manner in both alphabets. In contrast, strings that contain only *ambiguous* and *common* letters are *phonologically bivalent*. They can be pronounced in one way by treating the characters as Roman letters, and in a distinctly different way by treating them as Cyrillic letters. For example, the letter string POTOP can be pronounced as /potop/ if the ambiguous character *P* is interpreted according to its Roman pronunciation. By contrast, if the letter string is taken as a Cyrillic spelling, the grapheme *P* receives the pronunciation /r/ and the string must be pronounced /rotor/ (the characters *O* and *T* are common and have the same pronunciation in the two alphabets). In the case of POTOP, both pronunciations are legal Serbo-Croatian words (the former means "flood" and the latter, "rotor").

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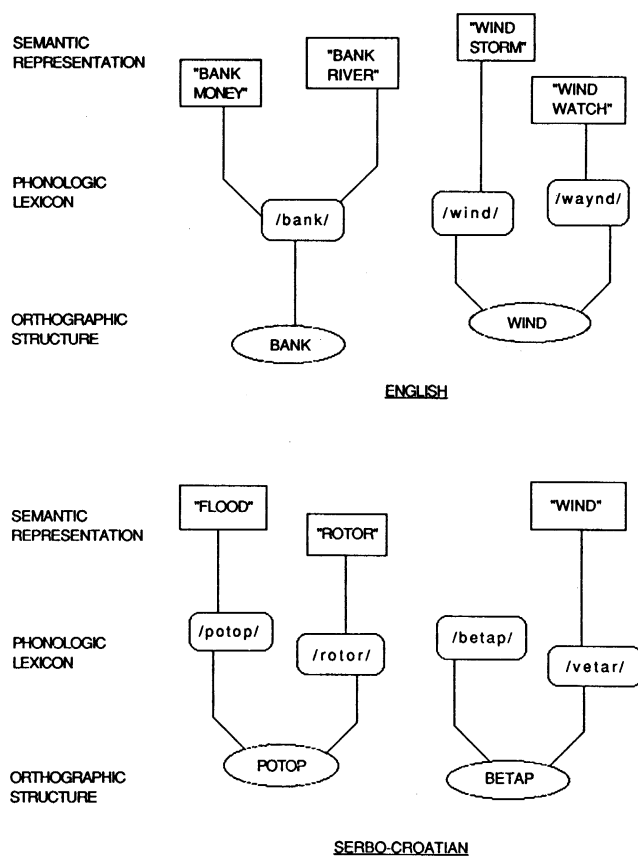


Figure 1. Different types of ambiguity in English and in Serbo-Croatian.

When a phonologically bivalent word of Serbo-Croatian is read in isolation, the alphabet is not specified by a context, and, therefore, the spelled form can be pronounced in two different ways. Two types of such bivalent strings exist. In one of these, both pronunciations are known to the reader as words (i.e., have lexical entries). Such letter strings are both phonologically *and* lexically ambiguous. In the other type, which occurs more frequently, only one of the two pronunciations is a word, while the other is a nonword. Such strings are phonologically ambiguous, but because they are related to only one lexical entry, they are not lexically ambiguous. An illustration of the various forms of ambiguity in Serbo-Croatian is presented on the bottom of Figure 1.

In the present study we exploited the bialphabetic property of Serbo-Croatian in order to assess the relative contributions of phonological and lexical ambiguity to interference in the process of word recognition. Specifically, our aim was to investigate whether there are conditions under which phonological ambiguity in the absence of lexical ambiguity is sufficient to impair performance or whether lexical ambiguity is a necessary condition for such interference when words are presented in isolation. This issue may have relevance, at least to some extent, to orthographies which represent phonology in an indirect manner (i.e., printed letter strings can be read

in more than one way). It focuses on whether phonologically ambiguous letter strings are processed differently regardless of the lexical status of the possible pronunciations.

Previous studies in Serbo-Croatian examined how fluent bialphabetic readers process ambiguous print. Lukatela, Popadic, Ognjenovic, and Turvey (1980) investigated lexical decision performance in Serbo-Croatian, comparing phonologically ambiguous and unequivocal words. They demonstrated that words that could be pronounced in two different ways were accepted more slowly as words, relative to words that could be read in only one way. Similar results were found by Feldman and Turvey (1983), who compared phonologically ambiguous and phonologically unequivocal forms of the same lexical items. This outcome was interpreted to suggest that, in contrast to English, lexical decisions in Serbo-Croatian are necessarily based on the extraction of phonology from print (Turvey, Feldman, & Lukatela, 1984).

The relative contributions of phonological and lexical factors were not directly assessed in these previous studies. However, although Lukatela et al. (1980) demonstrated that phonologically ambiguous letter strings incurred longer lexical decision latencies than did phonologically unequivocal strings, they did not find a significant difference in decision latencies between ambiguous strings with one or with two lexical entries. In fact, phonologically bivalent letter strings slowed subjects' responses (although to a lesser extent), even if the two possible readings of the letter strings represented two nonwords (see also Lukatela, Savic, Gligorjevic, Ognjenovic, & Turvey, 1978). Interestingly, words that were composed exclusively of common letters that were alphabetically bivalent but *phonologically unequivocal* did not slow lexical decisions, relative to their unique alphabet controls (Feldman & Turvey, 1983). Finally, the magnitude of the difference in decision latencies to bivalent and unequivocal forms of a word varied with the number of ambiguous letters in the bivalent form of that word (Feldman, Kostic, Lukatela, & Turvey, 1983; Feldman & Turvey, 1983). In general, these results suggested that the reader of Serbo-Croatian processes print by a phonologically analytic strategy that precedes lexical access. Consequently, as a rule, his or her performance is hindered by phonological ambiguity (see Feldman, 1987, for a review).

However, the conclusion that the phonologically analytic Serbo-Croatian reader is not sensitive to the lexical status of the different alphabetic readings may be premature. All of the above studies monitored either lexical decisions or naming of isolated words. These tasks may not have been sensitive enough to detect lexical effects. In particular, they may not have detected differences in the processing of phonologically ambiguous letter strings which represented one as contrasted with two words. Lexical decisions of isolated words can be made on a fast familiarity judgment (whether visual or phonological) that is based on a prelexical superficial recognition process, not necessarily involving lexical access (see Balota & Chumbley, 1984, 1985, for a discussion of this point). In contrast to lexical decision, the naming task may require a deeper phonological processing, but it does not necessarily reveal whether an alternative word, other than the reader's



final choice, had been considered during the process of phonological disambiguation.

In a recent study Lukatela, Turvey, Feldman, Carello, and Katz (1989) examined whether a presentation of semantic context can override an ambiguous alphabetic context. They have shown that the correct and consistent alphabetic assignment for a letter string can indeed be offset by previously accessed lexical entries (that are activated by semantic information). Hence, in contrast to the previous conclusions of Turvey et al. (1984), who suggested that a prelexical phonological analysis of print is mandatory in Serbo-Croatian, these results demonstrate that the Serbo-Croatian reader can also be affected by the lexical characteristics of the printed stimulus if the experimental conditions invite deeper processing. For the purpose of the present study, in order to assess the relative effects of lexical and phonological ambiguity on the process of word recognition, we needed a methodology that tapped more directly the process of mapping printed words into lexical phonological structures. Therefore, in the present experiments we employed the matching task that was used in some of our previous studies for a similar purpose (Frost & Katz, 1989; Frost, Repp, & Katz, 1988).

### The Matching Task

In the matching task, subjects are simultaneously presented with a printed word (or a nonword) on a computer screen and with a spoken word (or a nonword) via headphones. The subject is asked to decide as fast as possible whether or not the stimuli presented in the visual and the auditory modalities are the same (positive response) or whether they are different (negative response). Our assumption is that the simultaneous presentation of visual and auditory words produces separate activations of the orthographic and the phonologic lexical systems that are at least *initially* independent. In order to match the spoken and the printed forms of words, they both have to be represented on the same metric, that is, to converge at an identical lexical entry. Theoretically, this entry can be either phonologic or orthographic. Thus, the matching of a spoken and a printed word can be achieved, either by recoding the print into a phonological representation and by comparing it with the phonological representation derived by the auditory channel or, alternatively, by recoding the spoken form into an orthographic code and by comparing it with the printed word. However, these two theoretical possibilities are not equally probable. The transformation of speech into an orthographic representation is, by far, less practiced than the transformation of spelling into phonology. Indeed, in a previous study which involved simultaneous presentation of print and speech, we have demonstrated that it is the printed word which is transformed into a detailed phonetic representation and that this process is very fast and automatic (Frost et al., 1988). Consequently, we assume that the common end result of both print and speech processing in the matching task is a *phonological* representation in the lexicon. The claim that the phonological representation is indeed lexical is supported by results in a previous study that used the matching task (in

English and Serbo-Croatian) in which word frequency effects were demonstrated, and differences were found between words and pseudowords (Frost & Katz, 1989).

The matching of an orthographic form to a spoken word might be performed in at least two different ways. One is to construct, at a first stage, functionally independent and complete phonological representations of the printed word and the spoken stimulus. These two representations are compared at a subsequent stage. This possibility is in accordance with Morton's separate auditory and visual input logogens (Morton, 1981). A second possibility is that the process of mapping the print into phonology and the process of mapping the spoken stimulus into the common phonological structure are weakly interactive. According to this alternative, the two processes share information before completing their respective analyses, and by doing so, alter the extent of each other's processing. Thus, seeing print and forming a partial phonological representation of it can confirm (or contradict) a match to the accumulating phonological information being received via speech. In a complementary way, the rapid accumulation of information about which phonemes could be represented by the print can be influenced by the phonological information that is being received simultaneously via the auditory channel. Consistent with the interactive view are results that show reduced but significant cross-modal priming of auditory recognition of printed words (Hanson, 1981; Kirsner, Milech, & Standen, 1983) and visual-auditory interference in a Stroop paradigm in the naming task (Tanenhaus, Flanigan, & Seidenberg, 1980). It is important to distinguish between these two alternative possibilities in order to understand how phonology is derived from print.

In the three experiments reported here, subjects were presented with printed and spoken words and were required to determine whether they are equivalent. The printed words were selected for the matching task so that in their printed form they were phonologically ambiguous in one condition (e.g., POTOP) and unequivocal in another condition (an unambiguous form of the same word, e.g., ROTOR, РОТОР). The spoken forms of the words presented auditorily were always (necessarily) unambiguous (e.g., /rotor/). Our primary aim was to determine the effects of phonological and lexical ambiguity. If phonological ambiguity in itself affects the process of word recognition, then the efficiency of the matching process should be directly influenced by the number of possible pronunciations for the printed word, regardless of the lexical status of the different pronunciations. If lexical ambiguity (whether a letter string has two meaningful pronunciations or only one) affects the matching process, then subjects' performance for phonologically ambiguous strings that are meaningful in both their Cyrillic and their Roman forms should be slower than phonologically ambiguous strings that are meaningful in only one alphabet. In both instances, performance will be assessed by computing the difference between latencies for matching the spoken words to the bivalent and unequivocal printed forms of the same word. An additional aim of the present study was to examine the sequence of the early stages of the matching process. Hence, we introduced an additional experimental manipulation that consisted

of slowing the process of generating phonological information from speech by degrading the spoken presentation.

### Experiment 1

In Experiment 1 we presented subjects with phonologically bivalent letter strings that could be read as a word or as a nonword and with bivalent strings that could be read as two legal words (the former strings were phonologically but not lexically ambiguous, whereas the latter were ambiguous at both the phonological *and* the lexical level). In the present experiment, when a lexically ambiguous letter string was presented in print, its *high-frequency* (dominant) reading was always presented auditorily as the matching referent. Similarly, the dominant alternative was always depicted when the unequivocal printed form of the same letter string appeared. The purpose of the experiment was to investigate whether lexical ambiguity is indeed perceived and affects the reader's performance even when the dominant reading of the bivalent letter string is presented.

A second aim of the present study was to investigate the time course of processing the printed and the spoken word by examining the interaction of auditory degradation with phonological and lexical ambiguity. If the subject derives the phonological representation of the auditory input independently of information coming from the visual channel, then the effect of auditory degradation should be equivalent when the printed stimulus is phonologically ambiguous and when it is not; in other words, the effects of degradation and ambiguity should be additive. Auditory degradation will slow the process of retrieving the phonological structure from the phonetic input, but this reduction in the amount of phonological information will have no effect on the generation of phonology from the print. On the other hand, if the partial phonemic information arriving on the auditory channel facilitates the selection of a phonemic value for those graphemes that are phonologically ambiguous (before the spoken word is fully analyzed), then the effects of degradation and phonological ambiguity should interact: The matching of letters to their respective phonemes will be slower for the phonologically ambiguous letters than for the unequivocal letters (see Frost & Katz, 1989; Frost et al., 1988, for a discussion of the simultaneous presentation with degradation technique).

### Method

*Subjects.* Forty undergraduate students from the University of Belgrade, all native speakers of Serbo-Croatian, participated in the experiment for course credit.

*Stimuli and design.* A total of 120 pairs of words were used in the experiment. A pair consisted of a visual and an auditory presentation of a word. In 60 pairs, the printed and the spoken words were the same, and in 60 pairs they were different. The 60 same pairs included our target words, and the 60 different pairs were introduced as fillers in order to achieve a probability of .5 for a *same* response.

The printed words were presented in Cyrillic or Roman characters and appeared either in a phonologically bivalent form or in a phonologically unequivocal form. Of the phonologically bivalent target words, 20 had two meaningful pronunciations, one in each alphabet (usually belonging to the same syntactic class), and 20 had only one

meaningful pronunciation, half Roman and half Cyrillic, the other being a nonword. In addition there were 10 unequivocal fillers in each alphabet. In summary, the Roman and the Cyrillic scripts were mixed equally in all experimental conditions.

Obviously, the auditory form was always phonologically unequivocal. For the lexically ambiguous letter strings (i.e., those that had two possible meaningful pronunciations), the spoken form was always the *higher frequency* (dominant) lexical alternative. Because there is no standard frequency count in Serbo-Croatian, the relative frequencies of the two pronunciations were assessed by 30 native speakers. They were presented with the phonologically unequivocal printed forms of the high- and the low-frequency alternatives and were requested to decide for each pair which alternative was more frequent. On the basis of this judging procedure, we selected 20 ambiguous words for which there was at least 75% agreement across judges on which alternative was the dominant meaning. Thus, the auditory stimulus always matched the higher frequency alternative of the printed bivalent word. For the phonologically bivalent but lexically unequivocal letter strings, the spoken form always was the lexical (meaningful) alternative, not the nonword. The experimental design is summarized in Table 1.

Mismatched trials were constructed by pairing two words with the same length and vowel-consonant structure but which differed with respect to one or two phonemes. The position of the nonidentical segments was distributed across words uniformly. Half of the visually presented trials were in Roman and half in Cyrillic. Auditory degradation was introduced in the experiment as an additional factor. Each subject heard an equal number of degraded and undegraded stimuli, and this condition was counterbalanced across subjects.

Four test lists were created, each containing all four combinations of ambiguity and degradation: For each subject, a word could appear in either its phonologically ambiguous form or its unequivocal form with an auditory version that either was or was not degraded by noise. Each test list contained all four combinations of different items, and across lists a given word appeared in each of the four conditions. Each subject was tested with only one list. This design allowed us, first, to compare the effects of phonological ambiguity (one or two possible pronunciations) with the effects of lexical ambiguity (one or two meaningful pronunciations of the printed word) and, second, to examine whether auditory degradation interacted with either phonological ambiguity or lexical ambiguity.

The visual stimuli were presented on a Macintosh computer screen. They subtended a visual angle of approximately 2.5° on average. The auditory stimuli were originally spoken by a male native speaker in an acoustically shielded booth and recorded on an Otari MX5050 tape recorder. The speech was digitized at a 20-kHz sampling rate. Each digitized stimulus was edited by using a digital waveform editor. Its onset was determined visually on an oscilloscope and was verified auditorily through headphones. A mark tone was then inserted at the onset of each stimulus. The digitized edited stimuli were recorded at 3-s intervals on a two-track audiotape, one track containing the

Table 1  
*Example of Words in the Experimental Design*

One meaningful pronunciation			Two meaningful pronunciations		
Unequivocal print	Bivalent print	Auditory stimulus	Unequivocal print	Bivalent print	Auditory stimulus
VETAR	BETAP	/vetar/	ИІОТІІ	POTOP	/potop/

*Note.* The Roman reading of BETAP is /betap/, which is a nonword. In contrast, the Cyrillic reading of POTOP is /rotor/, which is indeed a word.

spoken words while the other track contained the mark tones. The purpose of the mark tone was to trigger the presentation of the printed word on the computer screen.

Auditory degradation was achieved by masking each spoken stimulus with signal-correlated noise—that is, white noise with the same amplitude envelope as the spoken stimulus (Schroeder, 1968). Speech and noise were added digitally in proportions of .3 and .7, corresponding to a constant signal-to-noise ratio of  $-7.5$  dB. The use of signal-correlated noise ensured that the characteristics of the auditory degradation were equivalent for all of the stimuli.

*Procedure and apparatus.* Subjects wore headphones and sat in a semi-darkened room in front of the computer screen. The experimental task consisted of pressing a *same* key if the visual and the auditory stimuli were the same word and pressing a *different* key if they were different. The dominant hand was always used for the *yes* response.

The audiotape containing the verbal stimuli and the mark tones was played on a two-channel Sony tape recorder. The verbal stimuli were transmitted binaurally to the subject's headphones. The mark tones were transmitted through an interface to the Macintosh, where they triggered the visual presentation and the computer's clock for reaction time (RT) measurements. The experimental session began with 16 practice pairs. After the practice, all 120 test trials were presented in one block.

## Results and Discussion

Means and standard deviations of RTs for correct responses were calculated for each subject in each of the experimental conditions. Within each subject-condition combination, outliers that were greater than two standard deviations from the mean were eliminated. Outliers accounted for less than 5% of all responses. This procedure was repeated in all three experiments of the present study.

For the sake of clarity, we will hereby define the various effects that were assessed in our analyses. (a) The main effect of phonological ambiguity was measured by comparing RTs to words that were presented in their bivalent alphabet with RTs to the same words when presented in their unequivocal alphabet. (b) The main effect of lexical ambiguity reflects differing decision latencies to words that have two meaningful pronunciations in their bivalent form and words that have only one meaningful pronunciation. Note that this main effect is difficult to interpret because we are dealing here with two groups of words which differ in their respective frequencies. We will, therefore, ignore this main effect in our following analyses. A more meaningful comparison is (c) the interaction of lexical ambiguity, defined in terms of number of meanings, and phonological ambiguity, assessed in terms of the difference between bivalent and unequivocal forms. This interaction would suggest that phonological ambiguity is indeed more detrimental for words that have two meaningful pronunciations than for words that have only one. (d) The main effect of degradation reflects the different RTs for degraded and undegraded auditory stimuli. This main effect is, in fact, trivial. Of more interest is (e) the interaction of degradation with phonological ambiguity and lexical ambiguity.

RTs in the different experimental conditions are summarized in Table 2. Overall, RT was slower when words were printed in their phonologically ambiguous form than in their

unequivocal form. Moreover, the difference between ambiguous and unequivocal forms appeared to be larger when the bivalent words had two meaningful pronunciations, rather than one. Finally, the effects of auditory degradation were quite similar in all experimental conditions.

To assess the statistical significance of these trends, we performed an analysis of variance (ANOVA) across subjects ( $F_1$ ) and across stimuli ( $F_2$ ), with the main factors of phonological ambiguity (unequivocal or phonologically bivalent print), lexical ambiguity (one meaningful pronunciation or two), and degradation (normal or degraded presentation). The main effects of phonological ambiguity and degradation were significant,  $F_1(1, 39) = 61.3$ ,  $MS_e = 164,054$ ,  $p < .001$ ;  $F_2(1, 19) = 26.2$ ,  $MS_e = 96,485$ ,  $p < .001$ ; and  $F_1(1, 39) = 20.7$ ,  $MS_e = 234,155$ ,  $p < .001$ ;  $F_2(1, 19) = 18.2$ ,  $MS_e = 87,701$ ,  $p < .001$ , respectively. The interaction of lexical ambiguity and phonological ambiguity was marginally significant,  $F_1(1, 39) = 3.07$ ,  $MS_e = 207,802$ ,  $p < .08$ ;  $F_2(1, 19) = 2.05$ ,  $MS_e = 138,633$ ,  $p < .1$ . The effect of degradation did not interact with either print or lexical ambiguity ( $F_1, F_2 < 1.0$ ). The three-way interaction was also nonsignificant ( $F_1, F_2 < 1.0$ ).

We analyzed the percentage of errors in a separate analysis of variance. The results are similar to the RT analysis and are presented in Table 2. The main effects of phonological ambiguity and degradation were significant,  $F_1(1, 39) = 3.6$ ,  $MS_e = 24.6$ ,  $p < .06$ ;  $F_2(1, 19) = 5.10$ ,  $MS_e = 17.5$ ,  $p < .03$ ; and  $F_1(1, 39) = 11.0$ ,  $MS_e = 12.0$ ,  $p < .001$ ;  $F_2(1, 19) = 8.65$ ,  $MS_e = 10.5$ ,  $p < .008$ , respectively. The interaction of phonological ambiguity and lexical ambiguity was marginally significant in the subject analysis,  $F_1(1, 39) = 3.40$ ,  $MS_e = 26.1$ ,  $p < .07$ , but highly significant in the stimuli analysis,  $F_2(1, 19) = 8.65$ ,  $MS_e = 13.6$ ,  $p < .008$ . Again, degradation did not interact with the other factors.

Although the results were not fully consistent, they suggest that phonological ambiguity affected word recognition: If a letter string could be pronounced in two ways, subjects' performance was slowed, even when only one of those pronunciations was a real word. It is important to emphasize that because the unequivocal and ambiguous forms were related to the same word, differences between these two forms cannot be related to differences in their relative frequency. If anything, the cumulative frequency for the bivalent form was higher than for the unequivocal form (see also Feldman et al., 1983). The effect of phonological ambiguity appeared to be even larger when the ambiguous printed stimulus could have been read as two meaningful words than when it could be read in only one meaningful way. However, this interaction was more pronounced in the error analysis.

The effects of auditory degradation provide additional insights concerning the interaction of the visual and the auditory systems in word recognition. Clearly, auditory degradation of the spoken stimulus resulted in an overall slowing of subjects' responses. However, this effect was additive and did not interact with phonological or lexical ambiguity. This result suggests that, at least in the processing of high-frequency words, the extraction of phonemic information from the auditory signal is performed independently of the visually based processing of the words presented in print. In Experiment 2, we determine if this outcome can be generalized to

**Table 2**  
*Matching Reaction Times (RTs, in Milliseconds) and Percentages of Errors (PEs) for Words Printed in Unequivocal or Bivalent Print, Under Normal or Degraded Auditory Presentations*

Presentation	One meaningful pronunciation					Two meaningful pronunciations				
	Print				Bivalence effect	Print				Bivalence effect
	Unequivocal		Bivalent			Unequivocal		Bivalent		
RT	PE	RT	PE	RT	PE	RT	PE	RT	PE	
Normal	740	4	787	5	47	707	5	778	12	71
Degraded	780	8	817	7	37	751	11	823	17	72

*Note.* Bivalent words had either one or two lexical entries in their bivalent forms. The dominant alternative was presented auditorily.

the perception of the low-frequency alternative reading of bivalent words.

### Experiment 2

The effects of lexical ambiguity revealed in Experiment 1 may have been attenuated because only the high-frequency lexical alternative of a phonologically bivalent word was presented to the subject. It is possible that when the lexical alternatives of a bivalent letter string are discrepant in frequency, only the dominant alternative is activated sufficiently, and therefore lexical ambiguity does not have a strong effect on the process of word recognition. This could have resulted in a considerable reduction of the ambiguity effect, thereby attenuating the interaction between phonological ambiguity and lexical ambiguity observed in Experiment 1.

Our aim in Experiment 2 was to examine the effect of phonological ambiguity and its interaction with lexical ambiguity and auditory degradation when the *low-frequency* (subordinate) alternatives are presented as unequivocal controls.

### Method

*Subjects.* Forty undergraduate students from the University of Belgrade, all native speakers of Serbo-Croatian, participated in the experiment for credit. None of them had participated in Experiment 1.

*Stimuli and design.* The stimuli, design, procedure, and apparatus were identical to those used in Experiment 1, except that when the bivalent words had two meaningful pronunciations, the *low-frequency* meaning was presented auditorily as the matching referent and as the unequivocal printed control.

### Results and Discussion

RTs and errors in the different experimental conditions are summarized in Table 3. As in Experiment 1, we performed an ANOVA across subjects ( $F_1$ ) and across stimuli ( $F_2$ ) to assess the relative effects of phonological ambiguity, lexical ambiguity, and auditory degradation.

The main effects of phonological ambiguity and auditory degradation were significant,  $F_1(1, 39) = 115$ ,  $MS_e = 295,386$ ,  $p < .001$ ,  $F_2(1, 19) = 96.3$ ,  $MS_e = 74,130$ ,  $p < .001$ ; and  $F_1(1, 39) = 37.7$ ,  $MS_e = 258,479$ ,  $p < .001$ ,  $F_2(1, 19) = 8.44$ ,  $MS_e = 286,057$ ,  $p < .01$ , respectively. The interaction of phono-

logical ambiguity and lexical ambiguity was highly significant,  $F_1(1, 39) = 55.2$ ,  $MS_e = 145,027$ ,  $p < .001$ ,  $F_2(1, 19) = 18.1$ ,  $MS_e = 94,976$ ,  $p < .001$ . Finally, as in Experiment 1, degradation did not interact either with phonological ambiguity ( $F_1, F_2 < 1$ ) or with lexical ambiguity ( $F_1 < 1.0$ ,  $F_2 = 1.6$ ).

Similar results were obtained in the error analysis. There was a significant main effect of phonological ambiguity,  $F_1(1, 39) = 28.2$ ,  $MS_e = 9.1$ ,  $p < .001$ ,  $F_2(1, 19) = 13.0$ ,  $MS_e = 7.0$ ,  $p < .001$ , and auditory degradation,  $F_1(1, 39) = 23.5$ ,  $MS_e = 7.8$ ,  $p < .001$ ,  $F_2(1, 19) = 20.7$ ,  $MS_e = 10.0$ ,  $p < .001$ . There was a significant interaction of phonological ambiguity and lexical ambiguity,  $F_1(1, 39) = 4.87$ ,  $MS_e = 10.0$ ,  $p < .03$ . Degradation did not interact with phonological ambiguity,  $F_1 < 1.0$ ,  $F_2 = 1.97$ , or with lexical ambiguity,  $F_1(1, 39) = 3.5$ ,  $MS_e = 16.8$ ,  $p < .07$ ,  $F_2(1, 19) < 1.0$ ,  $MS_e = 9.7$ ,  $p < .4$ .

Thus, the trends revealed in Experiment 1 were replicated in Experiment 2, but the differences were strongly enhanced. The effect of phonological ambiguity was three times larger for words that had two meaningful pronunciations than for words with only one. When this interaction is compared with the one obtained in Experiment 1, it is clear that the major difference occurs for stimuli that could be read as two legal words. Here, the effect of phonological ambiguity was twice as large as in Experiment 1 (approximately 140 ms, as compared with 70 ms in the previous experiment). The statistical significance of this difference was assessed by using a mixed-model ANOVA design, with the additional between-subjects factor of frequency. The three-way interaction of phonological ambiguity, lexical ambiguity, and frequency was indeed significant,  $F(1, 78) = 11.7$ ,  $MS_e = 4523$ ,  $p < .001$ .

In spite of the enhanced effects of phonological ambiguity and its interaction with lexical ambiguity, it is clear that the effect of auditory degradation was similar for phonologically bivalent strings with one and two meaningful pronunciations and for phonologically unequivocal words. This pattern was revealed in both the RT and error analyses and was, in fact, very similar to the pattern obtained in Experiment 1. This outcome is consistent with our claim that the processing of the degraded auditory information was completed independently of the visual input. Our results seem to suggest that a phonologically bivalent letter string was first recoded as (or activated) its dominant phonological alternative, which was then compared with the spoken word. Because, in the present experiment, the spoken word represented the subordinate alternative, the subject would first find a mismatch and only

Table 3

Reaction Times (RTs, in Milliseconds) and Percentages of Errors (PEs) When the Subordinate Alternative Was Presented Auditorily

Presentation	One meaningful pronunciation					Two meaningful pronunciations				
	Print				Bivalence effect	Print				Bivalence effect
	Unequivocal		Bivalent			Unequivocal		Bivalent		
RT	PE	RT	PE	RT	PE	RT	PE	RT	PE	Bivalence effect
Normal	749	1	801	3	52	749	10	894	14	145
Degraded	808	5	850	10	42	818	13	970	25	152

then would generate the less frequent alternative. This tendency might explain the poorer overall performance in the present experiment.

### Experiment 3

In both Experiments 1 and 2, we found that the degradation of the auditory input did not interact with phonological ambiguity or with lexical ambiguity. These results lead us to conclude that subjects constructed complete phonological representations of the printed and the spoken stimuli independently of each other. It is possible, however, that this outcome resulted from different time courses of lexical activation caused by the printed and the spoken words. Although the onsets of the visual and auditory presentations were simultaneous, all of the print information was available immediately, whereas the auditory information that constituted the spoken word was distributed over 400 to 500 ms of time. Thus, in Experiments 1 and 2, the auditory information effectively lagged behind the visual information. This basic difference between auditory and visual presentation could have caused the subject to process the print first and the speech subsequently and independently. A similar argument was proposed by Glucksberg, Kreuz, and Rho (1986), who suggested that in a cross-modal backward priming paradigm, a visual target word presented after the onset of an auditory prime word might affect the lexical interpretation of the auditory stimulus. The purpose of Experiment 3 was to investigate whether auditory degradation did not interact with phonological ambiguity because of the particular timing relation between visual and auditory stimulus presentations or whether the outcome we observed indeed reflects a more general strategy for processing bimodal verbal information.

In Experiment 3, the visual presentation was delayed by 200 ms, relative to the onset of the spoken word. (A lag of 200 ms is slightly shorter than the average recognition point of a two-syllable word presented auditorily—e.g., Marslen-Wilson & Tyler, 1980). Thus, the printed word was presented not at the onset of the spoken word but *during* its distributed presentation. If subjects had the tendency, in the first two experiments, to process the print first, the new timing relation should counteract this bias. As noted above, the purpose of this manipulation was to encourage parallel processing of print and speech in order to increase the possibility of interactive processing.

### Method

**Subjects.** Eighty undergraduate students from the University of Belgrade, all native speakers of Serbo-Croatian, participated in the experiment for credit. None of the subjects participated in the previous experiments. Forty of the 80 subjects (Group A) were tested with the stimuli of Experiment 1 (dominant alternatives), and the other 40 (Group B) were tested with the stimuli employed in Experiment 2 (subordinate alternatives).

**Stimuli, design, and procedure.** The stimuli, design, and apparatus were identical to those used in the Experiment 1 and 2. The procedure, however, differed in one important respect from the previous experiments: The visual presentation of the stimuli lagged from the speech onset by 200 ms, and the frequency of the lexical alternatives for spoken forms was manipulated between sets of subjects.

### Results and Discussion

RTs are summarized in Table 4. We conducted separate analyses of variance for subjects who were presented with the high-frequency spoken alternatives (Experiment 3a) and for subjects who were presented with the low-frequency spoken alternatives (Experiment 3b). Each analysis was performed across subjects ( $F_1$ ) and across stimuli ( $F_2$ ), with the main factors of phonological ambiguity, lexical ambiguity, and auditory degradation.

For the group presented with the dominant alternatives (Group A), the main effects of phonological ambiguity and degradation were significant,  $F_1(1, 39) = 55.4$ ,  $MS_e = 176,745$ ,  $p < .001$ ,  $F_2(1, 19) = 20.7$ ,  $MS_e = 128,627$ ,  $p < .001$ , and  $F_1(1, 39) = 25.6$ ,  $MS_e = 382,340$ ,  $p < .001$ ,  $F_2(1, 19) = 22.7$ ,  $MS_e = 121,110$ ,  $p < .001$ . The interaction of phonological ambiguity and lexical ambiguity was significant,  $F_1(1, 39) = 13.1$ ,  $MS_e = 170,770$ ,  $p < .001$ ,  $F_2(1, 19) = 4.37$ ,  $MS_e = 153,201$ ,  $p < .05$ . More important, just as in Experiments 1 and 2, degradation did not interact with lexical ambiguity or with phonological ambiguity ( $F_1, F_2 < 1.0$ ).

The error analysis revealed a significant effect of auditory degradation,  $F_1(1, 39) = 40.0$ ,  $MS_e = 22.7$ ,  $p < .001$ ,  $F_2(1, 19) = 46.7$ ,  $MS_e = 20.0$ ,  $p < .001$ , and a significant interaction of phonological ambiguity and lexical ambiguity,  $F_1(1, 39) = 5.9$ ,  $MS_e = 12.9$ ,  $p < .01$ ,  $F_2(1, 19) = 3.72$ ,  $MS_e = 20.8$ ,  $p < .06$ . No interaction with degradation was found ( $F_1, F_2 < 1.0$ ).

Similar results were obtained with the experimental group presented with the subordinate alternatives (Group B): All main effects were significant,  $F_1(1, 39) = 41.6$ ,  $MS_e = 281,833$ ,

Table 4

Reaction Times (RTs, in Milliseconds) and Percentages of Errors (PEs) When the Onset of the Dominant (Experiment 3a) and the Subordinate (Experiment 3b) Alternatives Was Presented Auditorily Before the Visual Form

Presentation	One meaningful pronunciation					Two meaningful pronunciations				
	Print				Bivalence effect	Print				Bivalence effect
	Unequivocal		Bivalent			Unequivocal		Bivalent		
RT	PE	RT	PE	RT	PE	RT	PE	RT	PE	
	Dominant									
Normal	637	1	666	1	29	580	6	658	9	78
Degraded	688	13	718	11	30	636	14	724	22	88
	Subordinate									
Normal	615	1	652	3	37	621	10	713	17	92
Degraded	688	11	723	17	35	700	20	781	30	81

$p < .001$ ,  $F_2(1, 19) = 17.3$ ,  $MS_e = 165,043$ ,  $p < .001$ ; and  $F_1(1, 39) = 36.4$ ,  $MS_e = 455,213$ ,  $p < .001$ ,  $F_2(1, 19) = 38.7$ ,  $MS_e = 118,930$ ,  $p < .001$ , for phonological ambiguity and auditory degradation, respectively. The interaction of phonological ambiguity and lexical ambiguity was significant,  $F_1(1, 39) = 7.93$ ,  $MS_e = 251,528$ ,  $p < .007$ ,  $F_2(1, 19) = 5.13$ ,  $MS_e = 84,984$ ,  $p < .03$ . As in all previous experiments, degradation did not interact with either phonological ambiguity ( $F_1, F_2 < 1.0$ ) or with lexical ambiguity ( $F_1, F_2 = 0.0$ ), nor was the third-order interaction significant ( $F_1, F_2 < 1.0$ ).

The error analysis revealed significant main effects only for (a) phonological ambiguity,  $F_1(1, 39) = 28.9$ ,  $MS_e = 11.8$ ,  $p < .001$ ,  $F_2(1, 19) = 5.53$ ,  $MS_e = 26.0$ ,  $p < .02$ , (b) lexical ambiguity,  $F_1(1, 39) = 69.0$ ,  $MS_e = 15.9$ ,  $p < .001$ ,  $F_2(1, 19) = 5.1$ ,  $MS_e = 35.7$ ,  $p < .03$ , and (c) auditory degradation,  $F_1(1, 39) = 45.6$ ,  $MS_e = 23.1$ ,  $p < .001$ ,  $F_2(1, 19) = 35.2$ ,  $MS_e = 26.1$ ,  $p < .001$ .

The results obtained in Experiment 3 are very similar to those obtained in Experiment 1 and 2. In general, delaying the printed information did not interfere with subjects' performance. Similar error rates were found for normal and delayed presentation, and the faster RTs in the delayed condition are, in fact, an artifact of delayed measurement onsets. (In all experiments, RTs were measured from print onset.) Regardless of which phonological alternative was presented auditorily, phonological ambiguity did affect subjects' performance. Moreover, the effect was stronger when the phonologically ambiguous words had two meaningful pronunciations than when they had only one. If we consider first the results obtained with the dominant alternatives, it appears that our experimental manipulation actually enhanced the interaction between phonological ambiguity and lexical ambiguity obtained in Experiment 1. Whereas the statistical significance of these trends was unclear in Experiment 1, Experiment 3a provides a reliable confirmation of this observed effect. Even when the subject hears the dominant alternative of a phonologically bivalent word, both lexical (and phonological) interpretations are automatically activated. Nevertheless, in spite of the enhanced effect found in Experiment 3a, degradation still did not interact with either phonological ambiguity or with lexical ambiguity. We conclude, again, that the two processes of generating phonological

representations from the visual and auditory input channels were independent.

The results obtained with the delayed visual presentation of the subordinate alternatives (Experiment 3b) suggest that the effect of phonological ambiguity for words with two meaningful pronunciations was reduced relative to the effect we found in Experiment 2. In order to assess the statistical significance of this difference, we conducted an analysis that compared directly the interaction of phonological and lexical ambiguity in Experiments 2 and 3b. We used a mixed ANOVA design with the additional between-subjects factor of lag. The analysis revealed that the three-way interaction of phonological ambiguity, lexical ambiguity, and lag was indeed significant,  $F(1, 78) = 5.1$ ,  $MS_e = 5,084$ ,  $p < .02$ . This outcome provides additional insights concerning the effect of lagged visual presentation on the disambiguation process. We will discuss this finding further in the General Discussion.

## General Discussion

The present study was designed to examine the effects of phonological ambiguity and lexical ambiguity in print on word recognition. In three experiments, we exploited a special property of the Serbo-Croatian language—its transcription to both the Roman and Cyrillic alphabet—in order to manipulate separately the phonological ambiguity of a printed word and the number of lexical entries it represents. Our subjects were presented simultaneously with a printed and a spoken word and were required to determine whether they were the same or different. The speed and the accuracy of matching the printed and the spoken forms were measured when the print had either one possible pronunciation or two, and if two, when both pronunciations were real words or only one was. In addition, we examined whether auditorily degrading the spoken word interacted with either lexical or phonological ambiguity.

Across experiments, we manipulated the frequency of the lexical alternatives represented by the phonologically bivalent word, as well as the temporal interval between the onset of the speech and the print. A consistent pattern of results

emerged throughout the study. First, both the number of possible pronunciations for a printed word and their lexical status affected word recognition. Second, these effects interacted: Phonological ambiguity had a greater effect when the bivalent form could be read as two legal words than when it could be read as only one. Third, auditory degradation never interacted either with print ambiguity or with lexical ambiguity. In addition, these effects were obtained regardless of the lexical alternative's frequency or the temporal onset of print presentation.

Previous studies using the lexical decision task examined how fluent bialphabetic readers of Serbo-Croatian process ambiguous print. These studies showed that phonologically bivalent letter strings, both words and nonwords, indeed incurred longer decision latencies than did different unequivocal strings. However, the effect of phonological ambiguity was similar for phonologically bivalent letter strings whether the string represented real words or nonwords (Lukatela et al., 1978, 1980). In contrast to these previous studies, our results suggest that the reader is affected not only by the number of possible pronunciations of a printed word but also by their lexical status. That is, print bivalence caused greater difficulties when both of the pronunciations were attached to lexical entries than when only one pronunciation was a real word. One advantage of the design employed in the present study is that it allowed us to demonstrate the relative contribution of lexical and phonological factors, by comparing subjects' performance for the *same* word presented in either a bivalent printed form or in an unequivocal printed form. We found, in all three experiments, that the inhibitory effect on reaction time caused by bivalent print was roughly twice as large for bivalent strings with two lexical entries as compared with bivalent strings with only one real word entry (the other pronunciation being a nonword).

As noted above, the discrepancy in results between the present and previous studies may be due to the different tasks that were employed. The matching task explicitly requires matching the printed and the spoken forms of a word. Effects of lexical ambiguity should arise whenever the printed letter string is recoded into more than one phonological form. In this case, two conflicting alternative representations will be matched with the phonological representation derived from the auditory input which is necessarily unambiguous. In contrast, lexical decisions can be made on a fast familiarity judgment (Balota & Chumbley, 1984, 1985), and naming can be performed by a selection of only one lexical candidate. One consequence of the different task requirements is that lexical decision and naming can be performed successfully on the basis of one complete representation. Therefore, our results seem to provide evidence that the matching task is more sensitive than the lexical decision and naming tasks for detecting effects of phonologically derived lexical ambiguity.

A large effect of lexical status was obtained in the present study: Phonological ambiguity hindered performance to a greater extent when both pronunciations were meaningful than when only one pronunciation was a word. This effect suggests that interference was caused by the conflict between the two lexical entries. Although lexical effects in phonological disambiguation have been demonstrated before in Serbo-

Croatian, they were studied only in a priming paradigm. That is, a prime that was either semantically or alphabetically related to one of the lexical entries contributed to the disambiguation process (Feldman, 1987). Similarly, Lukatela et al. (1989) have shown that prior lexical access can override the consistent assignment of an alphabet reading in cases where the target letter string contained illegal combinations of Roman and Cyrillic letters. Our results with the matching task suggest that lexical factors can also be demonstrated when bivalent strings are presented in isolation.

The influence of frequency provides additional insights concerning the processing of bivalent letter strings. When the subordinate alternative was presented auditorily, it inhibited the response to its matching but bivalent printed letter string: In Experiment 2 and 3b (which used the low-frequency spoken words), the difference between bivalent and unequivocal printed forms was greater than was the difference in Experiments 1 and 3a. This outcome suggests that subjects initially access the dominant alternative related to the bivalent printed string and that a mismatch between its phonological form and the subordinate form presented on the auditory channel was the cause for the longer RTs (and greater number of errors) encountered in these experimental conditions. These results are parallel to meaning frequency effects of homophonic homographs reported by Hogaboam and Perfetti (1975) and, overall, support frequency-ordered access models for lexically ambiguous words (e.g., Simpson, 1981; Simpson & Burgess, 1985).

In a task in which subjects had to find a polysemous word in a sentence, Hogaboam and Perfetti (1975) demonstrated that detection was faster when the context was related to the subordinate meaning of the ambiguous word than when it was related to the dominant meaning. Similar results have been recently reported by Neill, Hilliard, and Cooper (1988). In both studies, this outcome was interpreted to indicate that the more frequent or dominant meaning of a homograph was retrieved at an initial stage. Because the initially activated dominant meaning did not match the subordinate meaning which was suggested by the context, ambiguity was easily detected by the subjects. Evidence for the differential activation for high- and low-frequency meanings of ambiguous homographs was also demonstrated with event-related potentials (Van Petten & Kutas, 1987) and by monitoring eye movements (Duffy, Morris, & Rayner, 1988; Rayner & Frazier, 1989). These studies, however, examined the processing of homographs embedded in context. More relevant to our study are the results presented by Simpson and Burgess (1985), who examined the order of retrieving alternative meanings of *isolated* homographs. In their study, Simpson and Burgess found that the priority for accessing the alternative meanings was determined primarily by their relative frequencies: The more frequent meaning was retrieved at an initial stage, and the subordinate meaning was activated subsequently. The above studies with English materials examined the time course of activation of homophonic homographs with two meanings and a single pronunciation. Perhaps, the same principle of frequency-ordered access can be extended to the materials in the present study: heterophonic homographs with two meanings and two pronunciations.



Note, however, that the effect of print bivalence was obtained even when only the dominant meaning was appropriate and the subordinate meaning was irrelevant (Experiments 1 and 3a). Even though the spoken word in these experiments was the dominant meaning, we still found greater effects of print bivalence for words with two lexical entries over words with one lexical entry. This result invalidates the possibility that only one meaning, the more frequent lexical alternative, was generated from the bivalent letter string. Rather, it suggests that the subordinate alternative was activated as well, even when the dominant alternative was presented auditorily as the matching referent. The activation of the subordinate alternative hindered subjects' performance for words with two lexical entries because two lexical entries had to be considered instead of one.

In general, this outcome suggests exhaustive access to all meanings of ambiguous words and that these entries are automatically activated in the process of word recognition (e.g., Onifer & Swinney, 1981; Seidenberg, Tanenhaus, Leiman, & Bienkowsky, 1982). Our results further support a model in which both high- and low-frequency alternatives are indeed activated but not in parallel; their order of activation is determined by their relative frequency (Duffy et al., 1988; Neill et al., 1988).

It appears that the Serbo-Croatian reader processes print in a phonologically analytic manner. He or she is sensitive to the phonological ambiguity presented by the orthographic structure and derives from it both phonological forms. Nevertheless, the dominant alternative usually has an earlier or higher level of activation and, therefore, predominates over the subordinate alternative. However, this dominance effect can be reduced or reversed by priming the subordinate alternative of the print with the spoken (unambiguous) equivalent. This interpretation is supported by the effects of delaying the onset of the print in Experiment 3b.

In the delayed presentation of the subordinate words, the ambiguity effect observed in Experiment 3b was reduced almost by half relative to the effect obtained in Experiment 2. This result demonstrates that the spoken word was at least partially analyzed before the bivalent word was presented. The partially perceived subordinate spoken word enhanced the level of activation of its lexical representation, effectively priming the subordinate lexical entry. Ordered access models assume different time courses of activation for the dominant and the subordinate alternatives of ambiguous words (e.g., Simpson & Burgess, 1985; Van Petten & Kutas, 1987). Simpson and Burgess (1985) have shown that the dominant meaning of a polysemous homograph was activated as soon as 16 ms from stimulus onset, whereas the subordinate meaning was activated only 100 ms from stimulus onset. Our results suggest that the partial presentation of the spoken word prior to the printed stimulus enhanced the activation of subordinate alternatives which was triggered by the print, thereby reducing the frequency effect found in Experiment 3b by half, relative to Experiment 2. However, the 200 ms by which the auditory information preceded the visual information did not completely resolve the printed word's phonological or lexical ambiguity: Ambiguity effects still remained in the delayed

presentation. This outcome probably suggests that auditory lexical access was not completed within the 200-ms time period.

We now turn to the effects of auditory degradation. Superimposing noise on the auditory channel affected subjects' performance, but its effect was additive to the effects of phonological and lexical ambiguity, the spoken word's frequency, and the onset of print presentation. This outcome suggests that processing of the masked spoken words was independent of the printed information. Apparently, the build up of phonological information necessary for the perception of the spoken word proceeded without reference to information derived from the printed form.

Recently, Frost and Katz (1989) proposed a model that describes the mental lexicon as containing two levels of interactive relations between orthographic and phonological representations: One level contains the representations of letters and phonemes and relations between them. The other level involves whole printed and spoken words. The relations between spelling and sound in different orthographies (Serbo-Croatian as opposed to English, for example) was described in terms of structural differences that exist among the various languages in respect to the relation between the orthographic and phonological systems. In a similar way, phonological ambiguity can be characterized by complex, nonisomorphic connections between letters and phonemes, and lexical ambiguity can be characterized by ambiguous connections between the orthographic and the phonological systems at the level of whole words. The results of the present study provide additional information as to how the phonological and orthographic systems interact in a shallow orthography like Serbo-Croatian.

The additive effective of auditory degradation and print ambiguity suggests that the perception of spoken words was not penetrated by information from the orthographic system. When subjects heard degraded speech, the presence of potentially helpful (i.e., phonologically unambiguous) print did not, in fact, facilitate the match. Note that, because auditorily degraded and undegraded stimuli were randomly mixed, subjects could not have adopted one uniform strategy throughout the experimental session (e.g., favoring visual analysis when all stimuli were auditorily degraded). There are two possible explanations for the absence of such an interaction. Perhaps our previous suggestion that the orthographic and phonological systems exchange information at the level of single graphemes and phonemes (Frost & Katz, 1989; Frost et al., 1988) should be constrained to deep orthographies in which such an exchange might be beneficial. English could benefit from such interaction because in English some letters may represent more than one phoneme. Accordingly, the exchange of information between the visual and the auditory modalities at this level can provide the reader of English with additional information for resolving ambiguity. In contrast, in Serbo-Croatian, the simplicity of the relation between letter and phoneme may preclude any further improvement due to an interaction of printed and auditory information.

A second possibility for the absence of an interaction between phonological ambiguity and degradation is that the



perception of spoken words may be isolated from information derived from orthographic processing. (This may not be a mutual isolation; printed word perception may be informed at the subword level by the presence of a spoken word.) The idea of an independent spoken-word processor is consistent with the characterization of speech perception as modular, in the sense of Fodor (1983). It is also consistent with recent data from our laboratory suggesting that the simple detection of the presence or absence of speech in noise is not aided by the concurrent presence of a printed word that corresponds to the spoken word embedded in the noise (Frost et al., 1988).

Finally, we suggest that examining the effects of phonological and lexical ambiguity in Serbo-Croatian might provide insights into the difficulties faced by the reader of English. Although there are relatively few words in English that are phonologically bivalent for the skilled reader, there are many more that are phonologically ambiguous for the less skilled reader. The beginning reader of English often comes upon words that are, for him or her, of uncertain pronunciation. The reader may, therefore, decode a string into more than one possible phonological realization that maps onto more than one word in his or her lexicon. The ambiguity may sometimes be resolved by using contextual (i.e., semantic) information, but if the phonological information available to the reader is very reduced, even contextual information may not be enough. In either case, the process of lexical access for the less-skilled reader may be similar to the process followed by the skilled reader for phonologically bivalent words. Thus, the phonologically bivalent materials provide the researcher with a way to model natural reading for the unskilled reader by means of the skilled reader. One advantage of the present paradigm is that phonological bivalence for the skilled reader can be introduced and controlled experimentally.

## References

- Balota, D. A., & Chumbley, J. I. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. *Journal of Experimental Psychology: Human Perception and Performance*, 10, 340-357.
- Balota, D. A., & Chumbley, J. I. (1985). The locus of word frequency effects in the pronunciation task: Lexical access and/or production? *Journal of Memory and Language*, 24, 84-106.
- Duffy, S. A., Morris, R. K., & Rayner, K. (1988). Lexical ambiguity and fixation time in reading. *Journal of Memory and Language*, 27, 429-446.
- Feldman, L. B. (1987). Phonological and morphological analysis by skilled readers of Serbo-Croatian. In A. Allport, D. MacKay, W. Prinz, & E. Scheerer (Eds.), *Language perception and production* (pp. 198-209). London: Academic Press.
- Feldman, L. B., Kostic, A., Lukatela, G., & Turvey, M. T. (1983). An evaluation of the "basic orthographic syllabic structure" in a phonologically shallow orthography. *Psychological Research*, 45, 55-72.
- Feldman, L. B., & Turvey, M. T. (1983). Word recognition in Serbo-Croatian is phonologically analytic. *Journal of Experimental Psychology: Human Perception and Performance*, 9, 288-298.
- Fodor, J. A. (1983). *The modularity of mind*. Cambridge, MA: MIT Press.
- Frost, R., & Katz, L. (1989). Orthographic depth and the interaction of visual and auditory processing in word recognition. *Memory & Cognition*, 17, 302-311.
- Frost, R., Repp, B. H., & Katz, L. (1988). Can speech perception be influenced by a simultaneous presentation of print? *Journal of Memory and Language*, 27, 741-755.
- Glucksberg, S., Kreuz, R., & Rho, S. (1986). Context can constrain lexical access: Implications for models of language comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 12, 323-333.
- Hanson, V. L. (1981). Processing of written and spoken words: Evidence for common coding. *Memory & Cognition*, 9, 93-100.
- Hogaboam, T. W., & Perfetti, C. A. (1975). Lexical ambiguity and sentence comprehension. *Journal of Verbal Learning and Verbal Behavior*, 14, 265-274.
- Jastrebnsky, J. E. (1981). Multiple meanings, number of related meanings, frequency of occurrence, and the lexicon. *Cognitive Psychology*, 13, 579-595.
- Kirsner, K., Milech, D., & Standen, P. (1983). Common and modality-specific processes in the mental lexicon. *Memory & Cognition*, 11, 621-630.
- Kroll, J. F., & Schweickert, J. M. (1978, November). *Syntactic disambiguation of homographs*. Paper presented at the Nineteenth Annual Meeting of the Psychonomic Society, San Antonio, TX.
- Lukatela, G., Popadic, D., Ognjenovic, P., & Turvey, M. T. (1980). Lexical decision in a phonologically shallow orthography. *Memory & Cognition*, 8, 415-423.
- Lukatela, G., Savic, M., Gligorjevic, B., Ognjenovic, P., & Turvey, M. T. (1978). Bi-alphabetical lexical decision. *Language and Speech*, 21, 142-165.
- Lukatela, G., Turvey, M. T., Feldman, L. B., Carello, C., & Katz, L. (1989). Alphabetic priming in bi-alphabetic word perception. *Journal of Memory and Language*, 28, 237-254.
- Marslen-Wilson, W. D., & Tyler, L. K. (1980). The temporal structure of spoken language understanding. *Cognition*, 8, 1-71.
- Morton, J. (1981). The status of information processing models of language. *Philosophical Transactions of the Royal Society of London, B*, 295, 387-396.
- Neill, W. T., Hilliard, D. V., & Cooper, E. (1988). The detection of lexical ambiguity: Evidence for context-sensitive parallel access. *Journal of Memory and Language*, 27, 279-287.
- Onifer, W., & Swinney, D. A. (1981). Accessing lexical ambiguities during sentence comprehension: Effects of frequency of meaning and contextual bias. *Memory & Cognition*, 9, 225-236.
- Rayner, K., & Frazier, L. (1989). Selection mechanisms in reading lexically ambiguous words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 15, 779-790.
- Rubenstein, H., Lewis, S. S., & Rubenstein, M. A. (1971). Evidence for phonemic recoding in visual word recognition. *Journal of Verbal Learning and Verbal Behavior*, 10, 645-657.
- Schroeder, M. R. (1968). Reference signal for signal quality studies. *Journal of the Acoustical Society of America*, 43, 1735-1736.
- Seidenberg, M. S., Tanenhaus, M. K., Leiman, J. M., & Bienkowsky, M. (1982). Automatic access of the meaning of ambiguous words in context: Some limitations of knowledge-based processing. *Cognitive Psychology*, 14, 489-537.
- Simpson, G. B. (1981). Meaning dominance and semantic context in the processing of lexical ambiguity. *Journal of Verbal Learning and Verbal Behavior*, 20, 120-136.
- Simpson, G. B. (1984). Lexical ambiguity and its role in models of word recognition. *Psychological Bulletin*, 96, 316-340.
- Simpson, G. B., & Burgess, N. (1985). Activation and selection processes in the recognition of ambiguous words. *Journal of Experimental Psychology: Human Perception and Performance*, 11, 28-39.

- Tanenhaus, M. K., Flanigan, H. P., & Seidenberg, M. S. (1980). Orthographic and phonological activation in auditory and visual word recognition. *Memory & Cognition*, 8, 513-520.
- Turvey, M. T., Feldman, L. B., & Lukatela, G. (1984). The Serbo-Croatian orthography constrains the reader to a phonologically analytic strategy. In L. Henderson (Ed.), *Orthographies and reading: Perspectives from cognitive psychology, neuropsychology, and linguistics* (pp. 81-89). Hillsdale, NJ: Erlbaum.

- Van Petten, C., & Kutas, M. (1987). Ambiguous words in context: An event-related potential analysis of the time course of meaning activation. *Journal of Memory and Language*, 26, 188-208.

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