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Automatic and Pre-lexical Computation of Phonology in Visual Word Identification

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Two experiments were conducted to evaluate the hypothesis that identification of a visually presented word involves phonological information that is activated pre-lexically and automatically. A backward masking paradigm was used in which a word target was followed by a pseudoword mask, followed in turn by a non-linguistic pattern mask. The stimulus materials were Serbo-Croatian. The pseudoword mask could share all but one phoneme in common with the target, or none; moreover, it could be printed in the same alphabet as the target (e.g. both stimuli printed in Cyrillic), or in the other alphabet (e.g. target in Cyrillic, mask in Roman). Word targets were always lower case, and pseudoword masks were always upper case. It was assumed that where a mask shares phonological information with the target it can compensate for the interruption in processing by continuing the activation of the phoneme units activated by the target. Such an effect would be pre-lexical because the phoneme units activated by the mask would be those activated previously during the incomplete processing of the target. Both experiments, using different onset asynchronies among the stimuli, found significantly higher levels of target identification for homophonous masking than for non-homophonous masking, in agreement with similar studies using English materials. It was also shown that alphabet congruity affected the magnitude of the phonological effect in a direction that supported an hypothesis of inhibition of the letter processing units of one alphabet by the unique letters of the other alphabet. The results were discussed in terms of phonology's role in mediating lexical access in Serbo-Croatian and English, and in terms of a network model of visual word identification in Serbo-Croatian.

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INTRODUCTION

A longstanding problem in the psychology of reading is whether or not the accessing of a written word's representation in the internal lexicon depends on the speech form of the word. Is the graphemic input recoded phonologically prior to lexical access, or does lexical access proceed in an unmediated fashion? Research with Serbo-Croatian, which uses a phonetically precise orthography, tends to favour the view that the speech form of a word is activated pre-lexically and automatically in visual word recognition (e.g. Feldman & Turvey, 1983; Lukatela et al., 1989a, b; Lukatela & Turvey, in press). In the present article, we seek further confirmation of the routine activation of phonology prior to lexical access.

Our previous research has used the methods of rapid lexical decision and, to a lesser degree, rapid naming. These methods rely on processing that is sufficiently complete to access the internal lexicon and may, therefore, be open to the criticism that the results obtained could be due to processes that arise subsequent to lexical access. This criticism would not apply with the same force to results obtained from visual masking situations. When a briefly exposed target word is followed closely in time by a pattern, the processing of the target word can be interrupted so that the information derived from the target is partial rather than full. If the temporal and intensity parameters of masking were such that the target word was identified rarely, then we would have to conclude that the performance level reflected the fact that the internal lexicon was accessed rarely. That is, the mask's effect was such that it frequently prevented processing from yielding enough information to access the target's lexical entry. Now, suppose that for the same physical parameters we found that a new masking stimulus, identical in visual complexity to the original mask, but related on some linguistic dimension to the target, resulted in a much higher level of target identification. Then we would have to assume that the rise in performance was brought about by the new mask contributing in some way to the processing of the target, specifically, to the processes needed for accessing the target's lexical representation.

The method employed in the present article, due to Naish (1980), follows the logic identified in the preceding paragraph. It entails the identification of briefly exposed target words under backward masking conditions with the following key features: The masks are (a) pseudowords, (b) phonologically related or unrelated to the targets, and (c) themselves followed by patterned stimuli to reduce their identification and, thereby, guessing strategies about target/mask relationships. The figural structure of the masks, and comparable intensities of the targets and masks, confine the masking effects on the targets to primarily central processes (Michaels & Turvey, 1979; Turvey, 1973). With respect to

Naish's (1980) procedure, Perfetti, Bell, and Delaney (1988) argued that if phonology is computed automatically, then phonological similarity between the mask and target will reduce the interruption of central processing normally induced by the mask. They reasoned that a phonologically similar mask will reinforce the phoneme processing units activated partially by the target. In contrast, a phonologically dissimilar mask will activate partially other phoneme units. If it is the case that word unit activation follows from phoneme unit activation, then a target preceding a phonologically similar mask will be identified better than a target preceding a phonologically dissimilar mask. The idea is that word units partially activated by a target will be activated further by a subsequent mask with common phonological properties. The outcomes of Naish's (1980) and Perfetti et al.'s (1988) experiments (both using native speakers/readers of English and English language materials) were in agreement with this prediction.

A recently formulated model of Serbo-Croatian word recognition focuses on the interactions within and among the levels of letter processing units, phoneme processing units, and word processing units (Lukatela et al., 1989b). It will be helpful to repeat the preceding masking argument in the context of this model.

According to the model, word identification is the product of a network of connected processing units. The connections among processing units for a single letter position honour the following assumptions. First, the letter units of the Cyrillic and Roman alphabets transcribing Serbo-Croatian constitute functionally distinct sets (Lukatela, Savić, Ognjenović, & Turvey, 1978a). Common to the upper case Roman and Cyrillic sets are the letter units corresponding to the letters E, A, O, J, K, M, and T. These letters are shared by the two alphabets. Each signifies the same phoneme in Roman and Cyrillic. In addition to this shared subset of letter units, the set of Cyrillic letter units consists of units corresponding to each of the letters that are unique to the Cyrillic alphabet, and units corresponding to each of the ambiguous letters. The upper-case ambiguous letters are H, P, B, and C. These letters signify different phonemes in the two alphabets. A similar structure is defined for the Roman letters. In addition to the shared subset of letter units, the set of Roman letter units consists of units corresponding to each of the unique Roman letters, and units corresponding to each of the ambiguous letters. A major idea is that at the level of letter units, each ambiguous letter is represented twice—once in the Cyrillic set and once in the Roman set.

The second assumption is that each letter unit connects to its corresponding phoneme unit. No phoneme units are duplicated. For the phoneme units connected to the shared unambiguous letter units, there is *one* letter unit connection per phoneme unit (e.g. A connects to /a/, E connects to /e/, and so on). For all other phoneme units, there are *two* letter unit connections per phoneme unit, i.e. each unique Cyrillic, each unique Roman, and each ambiguous letter unit, connects to a phoneme unit which is connected to one other letter unit (e.g. л and L both connect to /le/, Г and G both connect to /ge/, B and V both connect to /ve/, and so on). These letter unit–phoneme unit connections embody the letter–phoneme correspondence rules of the Serbo-Croatian language.

The third assumption is that, with the activation of phoneme units by letter units, a two-way interactive process is initiated between the phoneme unit and word unit levels. Word units in the proposed network reflect the phonemic precision of the orthography. Each word unit represents a particular ordering of phoneme units. In consequence, in this model, the accessing of word knowledge is seen to take place principally through the phoneme level to word level connections.

The preceding assumptions, as noted, are with respect to the organisation of connections between levels for the processing of a single letter position. The letter units–phoneme units organisation just described repeats for each letter position (cf. McClelland & Rumelhart, 1981). That is, if the model is addressing the processing of a five-letter word, then there will be five sets of letter units–phoneme units connections, one for each letter position. The most important assumption of the present model of single word processing is made with respect to the relations between these letter–phoneme organisations across letter positions. It is assumed that, across letter positions, there are multiple inhibitory connections in both directions between the unique letter units of one alphabet and the unique and ambiguous letter units of the other alphabet. When a unique Cyrillic (Roman) letter unit is activated by a stimulus letter in one position, then the activity in all Roman (Cyrillic) letter units in the other letter positions is reduced.

Let us now return to Naish's (1980) masking paradigm. A target stimulus written with unique letters can be expected to induce inhibition of the letter units of the other alphabet, to excite the phoneme units specified by its orthography, and to excite word units containing these phonemes. The degree to which the target does these things will depend on how much time elapses before the mask arrives. A pseudoword masking stimulus that is transcribed in the same alphabet as the target, and which shares all phonemes but one in common with the target, will reinforce the inhibitory activity, most of the phoneme unit activity, and most of the word unit activity, initiated by the target. A pseudoword mask in the other alphabet, and possessing no phonemes in common with the target, will reverse the inhibitory activity among letter units, and excite different phoneme units and, thereby, different word units. A phonologically similar, same alphabet mask, should yield higher target identification than a phonologically dissimilar, other alphabet mask but, more generally speaking, target word identification should be higher under phonologically similar masking conditions regardless of the alphabetic relation between the stimuli.

The model of Serbo-Croatian word processing sketched above suggests a further prediction that we will refer to as the alphabet priming hypothesis. Let us consider more closely the inhibitory process at the letter unit level. When target and mask differ in alphabet, the letter units for the mask will be activiated more slowly due to their previous inhibition by target letter units. Consequently, the mask will abrogate processing at the phoneme unit level more slowly. This retardation in mask processing will have two related effects in the context of Naish's (1980) paradigm. One effect is that the target's phoneme units will have more time to activate uninterruptedly the appropriate word unit candidates. The other effect is that the target's phoneme units will receive less of a boost from a mask with common phonemic constituents. These effects of an alphabetic difference between target and mask should show up in the data as follows:

1. Target identification will be higher when followed by a phonologically dissimilar mask in the other alphabet than when followed by a phonologically dissimilar mask in the same alphabet.
2. Target identification will be lower when followed by a phonologically similar mask in the other alphabet than when followed by a phonologically similar mask in the same alphabet.

In the two experiments reported, we manipulate the relations between target and mask stimuli in terms of phonology and alphabet, and we assess the effects of these relations at onset asynchronies of 40 msec (target to mask) and 40 msec (mask to pattern) (Experiment 1) and 20 and 20 msec (Experiment 2). In both experiments, we look for an effect of phonological similarity and the particular interaction between phonological similarity and alphabet identified in (1) and (2) above. Our expectation is that both experiments will show a phonological similarity effect, but that the second experiment with the shorter time scale will be more likely to reveal the interaction.

EXPERIMENT 1

We take advantage of certain features of written Serbo-Croatian to provide a strong test of pre-lexical computation of phonology in Naish's backward masking paradigm. First, visual similarity between a target and a phonologically similar mask is ruled out by presenting the two stimuli in different cases and different alphabets. As noted above, Serbo-Croatian has two writing systems, Roman and Cyrillic, that use mostly different letters to represent the phonemes of the language (see Lukatela & Turvey, 1980). Consequently, by combining the two alphabets and the two cases it is possible to transcribe a target word and its phonologically similar mask such that there are often no shared visual forms and at worst only one shared visual form. Secondly, because of the phonemic precision of the orthography, a word and its pseudoword rhyme will have exactly the same number of letters. This feature protects against the possibility of non-superimposition of target (e.g. nought) and mask (e.g. nort) which opens the door for visual explanations of the phonological effect (Naish, 1980). Thirdly, in English experiments, phonemic similarity involving pseudowords cannot always be defined unequivocally. English language experimenters have to use an operational definition, namely, whether or not the pseudowords in question produce a pseudohomophone effect in the lexical decision task (Humphreys, Evett, & Taylor, 1982). The present experiment uses word–pseudoword target–mask pairs for which the phonemic similarity relation is unambiguous. This feature follows from the facts that the Serbo-Croatian writing system is phonemically precise and that all letters in a word are pronounced. Thus, a word context that differs from a pseudoword target in one letter is phonemically identical to the target with respect to all letter positions but one.

Method

Subjects. A total of 16 high-school juniors from the Fourth Belgrade Gymnasium were paid for their participation in the experiment. They were assigned randomly to one of four counterbalancing groups according to their appearance at the laboratory.

Materials. A total of 56 target words were selected from the middle familiarity range of a word list established by an extended series of familiarity judgement tests (cf. Gernsbacher, 1984). These tests were run with other high-school juniors who did not participate in the experiment. All selected words were Serbo-Croatian masculine nouns in nominative singular, and they had the CVCVC structure. Twenty-eight target words were written in Cyrillic lower case (e.g. "**шешир**" means "the hat"), and 28 in Roman lower case (e.g. "labud" means "the swan"). All target words were paired with each of four mask types: (1) the same alphabet, homophonic; (2) the same alphabet, non-homophonic control; (3) the other alphabet, homophonic; and (4) the other alphabet, non-homophonic control. All mask types were pseudowords of the CVCVC structure, i.e. each mask was of the same length and structure as the target word. In same alphabet homophonic pairs, both the target and mask were written either

TABLE 1
Sample Stimuli used in Experiments

	Masking Pseudoword	
Target Word	*Phonologically Similar*	*Phonologically Dissimilar*
Same alphabet (Cyrillic–Cyrillic)		
шешир	ШЕШИЛ	РУЧАЗ
ручак	РУЧАЗ	ШЕШИЛ
Same alphabet (Roman–Roman)		
labud	LABUG	ŽIVOK
zivot	ŽIVOK	LABUG
Other alphabet (Cyrillic–Roman)		
шешир	SESIL	RUČAZ
ручак	RUČAZ	SESIL
Other alphabet (Roman–Cyrillic)		
labud	ЛАБУГ	ЖИВОК
zivot	ЖИВОК	ЛАБУГ

in the Cyrillic or in the Roman alphabet. The masking letter string was generated by replacing the final consonant of the target word. By this procedure, in each same alphabet homophonic pair, and in each other alphabet homophonic pair, only the final phoneme was not shared by the target and mask. Contrary to this, in all non-homophonic pairs, no phonemes/graphemes were shared by the target and mask. For example, as illustrated in Table 1, for the target "labud", the four mask types were LABUG (same alphabet, homophonic), ŽIVOK (same alphabet, non-homophonic control), ЛАБУГ (other alphabet, homophonic), and ЖИВОК (other alphabet, non-homophonic control).

In addition to the 56 experimental words, another set of 72 five-letter words was selected, also from the mid-familiarity range. This other set was used to prepare three groups of foils designed to protect against response biases that might be induced by repeating fixed relations between the experimental stimuli. The first group consisted of 20 identity word–word pairs in which the same word appeared both as the target and as the mask (e.g. dolar–DOLAR). The second group contained 20 initial different word–nonword pairs in which the initial consonant was not shared by the target and mask (e.g. zapad–FAPAD). The third group of foils had 32 blank field–word pairs in which a blank field preceded a five-letter word in the mask position (e.g. –KAZAN).

Design. A given subject never encountered a word or pseudoword in any of the pairs more than once, but every subject saw every type of pair. These conditions were met with four counterbalancing groups. In total, each subject saw 56 experimental plus 72 filler pairs ordered randomly.

Procedure. Subjects were seated comfortably before the cathode ray tube of an Apple IIe computer in a dimly lit room. Target words were displayed in lower case and pseudoword masks in upper case in a dark on light format. The target and pseudoword mask had nominal exposures of 40 msec each. These exposure durations are "nominal" rather than exact, because display changes in reality occurred within the standard 16-msec scan rate of the Apple Ile monitor. This means that all actual durations of the nominally 40-msec exposure varied in a random manner with a uniform probability between 40 and 56 msec, whereby the statistical mean exposure was 48 msec.

Each trial was initiated by a subject pressing the space bar on the keyboard. Then, a fixation point appeared in the centre of the screen and the subject heard a brief warning signal after which a target (or a blank field) appeared for the nominal 40-msec duration replacing the fixation point. The target was followed (with a zero interstimulus interval) by a pseudoword mask, which replaced the target. The pseudoword mask was presented for 40 msec and, then, it was substituted by a row of six hashes which remained on the screen until the next trial. The subject was instructed to write down on a prepared form the word he or she believed to have seen during the brief presentation of stimuli. The subject was encouraged to write, in default, just a single letter.

Results and Discussion

The mean percentages of correct identifications of experimental targets and their standard deviations are shown in Table 2. The percentages of experimental targets identified correctly were analysed twice, once with subjects and once with items as a random effect. The F tests were then combined using Clark's (1973) min F' procedure. A 2 (mask type, phonologically similar *vs* dissimilar) × 2 (alphabet, same *vs* other) analysis of variance was performed. Only the main effect of mask type was significant [min $F'(1,59) = 43.41$, $P < 0.001$], with the phonologically similar masks eliciting better identification of targets (59%) than the phonologically dissimilar masks (27%). The main effect of alphabet was not significant [min $F'(1,62) = 1.71$, $P < 0.2$], and neither was the interaction between mask type and alphabet [min $F'(1,63) = 2.91$, $P < 0.1$].

The results are in agreement with the primary hypothesis identified in the Introduction, and confirm the previous observations of Naish (1980)

TABLE 2
Mean Correct Identification (%) of the Test Targets, and Standard Deviations (%) in Experiment 1 as a Function of Phonological Similarity of Target and Mask, and Alphabet of Mask Relative to that of Target

	Phonologically Similar		*Phonologically Dissimilar*	
Alphabet	*M*	*S.D.*	*M*	*S.D.*
Same	66.37	15.76	27.26	17.44
Other	52.80	19.29	28.33	20.61

and Perfetti et al. (1988), i.e. masking was reduced under phonologically similar pseudoword masks. Naish (1980) had used onset asynchronies of 30 and 20 msec. Perfetti et al. (1988) used three different pairs of onset asynchronies. They found the strongest effects of phonological similarity with the pair of shortest onset asynchronies tested, namely 30 and 25 msec. Naish (1980) found a 14.5% effect, and Perfetti et al. (1988) a 22% effect (approximately). In the present experiment, the phonological similarity effect was 32%.

As noted above, we follow Perfetti et al. (1988) in assuming that this retroactive effect of a phonologically similar mask is on a process of identification that is incomplete at mask onset. Because the mask shares phonological information with the target, it compensates, in part, for the processing interruption it brought about by refreshing the phoneme units activated by the target and, thereby, the word units consistent with those phoneme units. The effect is pre-lexical because the phoneme units affected by the mask are those activated during the incomplete processing of the target.

With respect to the second hypothesis identified in the Introduction, we preface its evaluation by considering in more detail what is at issue in the manipulation of alphabet. When a pseudoword mask in upper case and a word target in lower case are written in the same alphabet, is the condition one of alphabet congruity or graphemic similarity? In the processing model laid out in the Introduction, alphabet is a variable of significance at the letter unit level of processing. At the letter unit level, the two alphabets are distinguished within the network, with inhibitory connections defined reciprocally between the letter units of the Roman alphabet and the letter units of the Cyrillic alphabet. Activation of a unique letter processing unit of one alphabet induces inhibition in the set of letter processing units of the other alphabet. Alphabet congruity of target and mask means that the mask will activate non-inhibited letter units; alphabet incongruity means that the mask will activate inhibited letter units.

Graphemic similarity can be understood in two ways, depending on the sense of the term grapheme. Henderson (1985), in a critical review, identifies two senses in which "grapheme" can be used. In sense 1, the grapheme is the minimal contrastive unit in a given writing system. In sense 2, a grapheme comprises a letter or letters that specifies a single phoneme in speech. From the point of view of sense 1, a phonemically similar target and mask that differ in alphabet are graphemically dissimilar; from the point of view of sense 2, a phonemically similar target and mask that differ in alphabet are graphemically similar. In either sense, an hypothesis of graphemic similarity of target and mask means that the mask will activate the same graphemic processing units as the target; graphemic dissimilarity means that the mask will activate different graphemic processing units.

Let us now look at the predictions from the two senses of grapheme, beginning with sense 1. If word units are activated by graphemic information, then we should expect that targets followed by masks that are phonemically similar and in the same alphabet (i.e. graphemically similar) should be identified better than targets followed by masks that are phonemically similar and in the other alphabet (i.e. graphemically dissimilar). We should also expect that for the two conditions of phonemically dissimilar masks (i.e. same alphabet and other alphabet), there should be no difference in target identification; both conditions lack graphemic similarity, by definition.

Let us now look at the prediction from sense 2. When two stimuli are phonemically similar, they are graphemically similar, regardless of the alphabet relation between them. Consequently, targets followed by masks that are phonemically similar and in the same alphabet, and targets followed by masks that are phonemically similar and in the other alphabet, should be identified with the same accuracy. Similarly, for the two conditions of phonemically dissimilar masks, there should be no difference in target identification; both conditions lack graphemic similarity, by definition.

In sum, with respect to the homophonous mask conditions of the present experiment, the sense 1 and sense 2 interpretations of graphemic similarity make different predictions; with respect to the non-homophonous mask conditions, they make the same prediction. With same alphabet/phonemically similar masks, the percentage identification was 66.1%; with other alphabet/phonemically similar masks, the percentage identification was 52.2%. The two conditions of non-homophonous masks yielded 26.3 and 28.1%. Although this pattern comports with the sense 1 hypothesis of graphemic similarity, there was no significant interaction between alphabet match and phonological similarity, and therefore it must be concluded that the 66.1% to 52.2% was not a significant difference.

With respect to the question of whether or not alphabet *per se* was a factor, rather than graphemic similarity in either sense 1 or sense 2, it will be recalled from the Introduction that the significance of alphabet would be shown by way of a particular kind of interaction between alphabet match and phonological similarity. Namely, that for the homophonous mask conditions, same alphabet should be superior to other alphabet, *but* for the non-homophonous mask conditions, other alphabet should be superior to same alphabet. The alphabet prediction for homophonous masks agrees with the sense 1 graphemic prediction. The alphabet prediction for non-homophonous masks agrees with neither the sense 1 nor the sense 2 predictions. We reiterate that the statistical analysis of the alphabet match by phonological similarity interaction did not find significance. On the basis of this first experiment, therefore, we cannot confirm the secondary hypothesis based on alphabet inhibition nor, relatedly, can we distinguish between the graphemic and alphabet interpretations of the alphabet manipulation.

EXPERIMENT 2

The second experiment repeats the design of the first but with briefer onset asynchronies among the three stimuli (target word, pseudoword mask, pattern mask). Our expectation is that the hypothesised alphabet match by phonological similarity interaction expected from the alphabet priming hypothesis is more pronounced under some parameters of stimulus presentation than others. The parameters in question are likely to be those at which processing time is so limited that the retarding of mask processing due to alphabet inhibition is not compensated by the mask's contribution

TABLE 3
Predictions of the Relative Mean Correct Target Identification for the Different Mask Conditions under Three Different Hypotheses[a]

Hypothesis	*Prediction*		
Alphabetical bias	SH > SNH	SH > OH	SNH < ONH
Sense 1 graphemic	SH > SNH	SH > OH	SNH = ONH
Sense 2 graphemic	SH > SNH	SH = OH	SNH = ONH

[a]SH, same alphabet homophonic; OH, other alphabet homophonic; SNH, same alphabet non-homophonic; ONH, other alphabet non-homophonic.

to phoneme unit activation. Our guess is that such parameters comprise an extremely brief onset asynchrony between the word and the following pseudoword, and an extremely brief onset asynchrony between the pseudoword and the following pattern.

In Experiment 2, the onset asynchronies were half those of Experiment 1. It was hoped that the data obtained at these onset asynchronies would distinguish among the two graphemic similarity hypotheses and the alphabet priming hypothesis. The predictions of the three hypotheses are summarised in Table 3. With respect to the major hypothesis of a phonological similarity effect, it was expected that Experiment 2 would replicate the results of Experiment 1.

Method

Subjects. A total of 20 high-school juniors from the Fourth Belgrade Gymnasium were paid for their participation in the experiment. They were assigned randomly to one of four groups according to their appearance at the laboratory. None of them participated in Experiment 1.

Materials and Design. These were the same as for Experiment 1.

Procedure. The same procedure as Experiment 1 was used, except that the onsets of the word target and the pseudoword mask, and the onsets of the pseudoword mask and the pattern mask, were separated by a nominal 20 msec.

Results and Discussion

The mean percentage of correct identifications of experimental targets and their standard deviations are shown in Table 4. A 2 (mask type, phonologically similar *vs* dissimilar) × 2 (alphabet, same *vs* other) analysis of variance proved that the main effect of mask type was significant [min $F'(1,45) = 15.49$, $P < 0.001$], with the phonologically similar mask type eliciting better identification of targets (28%) than the phonologically dissimilar mask type (10%). The main effect of alphabet was not significant (min $F' < 1$), but the interaction between mask type and alphabet reached significance [min $F'(1,68) = 4.18$, $P < 0.05$]. Protected *t*-tests showed that between same alphabet homophonic pairs and other alphabet homophonic pairs there was no statistical difference (min $F' < 1$). For non-homophonic pairs, however, the analysis revealed a significant difference between same alphabet and other alphabet conditions [min $F'(1,74) = 3.85$, $P < 0.05$]. Correct identification of the target words occurred more frequently in the

TABLE 4
Mean Correct Target Identification (%) and Standard Deviation (%) in Experiment 2 as a Function of Phonological Similarity of Target and Mask, and Alphabet of Mask Relative to that of Target

	Phonologically Similar		*Phonologically Dissimilar*	
Alphabet	*M*	*S.D.*	*M*	*S.D.*
Same	32.14	20.66	7.14	8.03
Other	24.29	16.45	13.57	7.29

other alphabet condition (13.6%) than in the same alphabet condition (7.1%).

The present experiment reinforced the phonological similarity effect in backward masking observed in Experiment 1, and in the experiments of Naish (1980) and Perfetti et al. (1988). In addition, it confirmed the secondary hypothesis identified in the Introduction, a hypothesis that was derived specifically from the model of Serbo-Croatian word processing (Lukatela et al., 1989b): The effect of phonological similarity was less when the word target and pseudoword mask were printed in different alphabets than when they were printed in the same alphabet. More specifically, in non-homophonous mask conditions, pseudoword masks printed in the other alphabet produced superior target identification than pseudoword masks printed in the same alphabet. This outcome favours the view that the manipulation of alphabet in the two experiments was not a manipulation of graphemic similarity in either sense 1 or sense 2 (see Table 3). It adds to a number of other results with Serbo-Croatian materials that suggest a rapidly established, but short-lived, inhibition of letter processing units in terms of alphabet affiliation: The presentation of unique Roman letters induces inhibition of the Cyrillic letter-to-phoneme correspondences; the presentation of unique Cyrillic letters induces inhibition of the Roman letter-to-phoneme correspondences (Lukatela et al., 1989a, b).

GENERAL DISCUSSION

The present results can be viewed as a demonstration that information about the phonology of a printed word becomes available (a) prefatory to lexical access and (b) automatically. A higher level of target identification under homophonic masking relative to non-homophonic masking can be said to reflect the continued activation, under homophonic masking, of phoneme units activated initially in the incomplete processing of the target.

With respect to the autonomy claim, the design of the experiments did not encourage phonemic recoding—asking only that subjects write down what they saw—nor did it provide an opportunity for task-specific strategic processes—such as guessing a target on the basis of its homophony with the mask. Across stimuli, the homophonous masks were paired equally often with phonemically dissimilar targets. Moreover, the pseudoword masks were themselves masked.

There is some consensus that English word identification usually proceeds without recourse to phonology, and that the activation of phonological information is optional (Humphreys & Evett, 1985). Evidence occasionally obtained in lexical decision experiments for the involvement of phonological properties is attributed to post-lexical processes. The earlier results of Naish (1980), and the recent results of Perfetti et al. (1988) and van Orden (1987; van Orden, Johnston, & Hale, 1988), do not concur with the consensus view, however. In van Orden's experiments, subjects had to decide whether or not a printed word was a member of a given semantic category. Categorisation errors were observed frequently when homophones of category instances were presented (e.g. *rows* is homophonic with *rose*) and subjects tended to categorise *rows* as a flower more so than its spelling control *robs*. Further, false positive errors to nonword homophone foils (e.g. *sute* for *an article of clothing*) exceeded false positive errors to non-homophonic nonword spelling controls; the phonological characteristics of the nonword foils proved to be critical. Van Orden and his colleagues interpreted these results as demonstrating a strong pre-lexical phonological component in visual word identification. Given (a) the parallelism between the results in the English language studies of Naish and Perfetti et al., and the present results with Serbo-Croatian, and (b) the converging experimental evidence that Serbo-Croatian word identification is phonologically mediated, it seems prudent to suggest that for both orthographies lexical access depends on pre-lexical phonological information. Phonological mediation may be true for English and for Serbo-Croatian, but the evidence is, apparently, harder to come by in experimental studies with the English orthography.

If visual word processing in both Serbo-Croatian and English is phonologically mediated, then the data differences between Serbo-Croatian and English studies must reflect differences that arise within the mechanism of phonological coding, and not differences that arise from contrasting ways (visual *vs* phonological) of accessing word information. Van Orden (1987) suggests that the mechanism that connects orthographic and phonological features is sensitive to the co-variation between these two kinds of features across many words. The associative weights established between orthographic and phonological features would be determined by both the frequency and the consistency of co-variation. Serbo-Croatian and English differ in the co-variation of orthographic and phonological features, a difference that is captured by the contrast of shallow and deep orthography (Lukatela & Turvey, 1980). A difference in co-variation (in frequencies and consistencies of relations) between the languages would induce a difference in the mechanism of pre-lexical phonology.

To date, the evidence for pre-lexical phonology in Serbo-Croatian visual word processing has been derived from two major strategies. One strategy exploits the special phonological ambiguity that arises in written Serbo-Croatian by virtue of the two, partially overlapping alphabets used to transcribe the language. The other strategy is based in the class of priming effects that are produced when a target word is preceded by a word similar to the target on one or more dimensions. Let us consider first the strategy based on the fact that Serbo-Croatian has two writing systems, Roman and Cyrillic. As noted above, these two alphabets share a number of letters, some of which designate one phoneme in one alphabet and another phoneme in the other alphabet (Lukatela & Turvey, 1980). There are written words in Serbo-Croatian that are composed of only shared letters. Some of these words contain phonemically ambiguous letters. Take BETAP as an example. Read strictly through the letter-to-sound correspondences of the Cyrillic alphabet, this letter string is pronounced /vetar/ and is a high-frequency noun meaning "wind". Read strictly through the letter-to-sound correspondences of the Roman alphabet, BETAP is pronounced /betap/, a pseudoword. Read with a mixture of the two sets of correspondences, Cyrillic and Roman, leads to the pronunciations /vetap/ and /betar/, which are also pseudowords. The word meaning "wind" is transcribed in the Roman alphabet as VETAR. This letter string supports only a single reading, /vetar/. No other readings are possible. VETAR, unlike its Cyrillic mate BETAP, is phonologically unambiguous. In sum, the primary distinction between a BETAP-type word and a VETAR-type word lies in the greater number of phonological descriptions supportable by BETAP's letter structure.

In the lexical decision, the acceptance latencies for BETAP, and for words like it, are considerably longer than the acceptance latencies for VETAR, and for words like it, even though BETAP and VETAR are equal in frequency, syllabic structure, number of letters, and meaning. This contrast defines what is referred to as the phonological ambiguity effect. It is argued that accepting BETAP as a word is made more difficult by the fact that it activates more phoneme units than VETAR which, in turn, activate partially many more competing word units than VETAR (Lukatela et al., 1989b). Importantly, the phonological ambiguity effect satisfies a major criterion advanced by Coltheart, Davelaar, Jonasson, and Besner (1977) and van Orden (1987) for the demonstration of phonological mediation in lexical access, namely, that phonological effects be demonstrated empirically in *positive* lexical decisions. A summary of the varied empirical phenomena associated with the phonological ambiguity effect that implicate an automatic computation of phonology are to be found in Lukatela and Turvey (1990).

The other major strategy that we have used to address pre-lexical phonology is that of evaluating the effects on rapid naming and lexical decision of phonological similarity between a target word and the word context that precedes it. Hillinger (1980) found that, in lexical decision, word sequences such as EIGHT–MATE resulted in shorter decision times for MATE than coresponding control sequences, suggesting that MATE benefited from the phonological information activated by EIGHT. This result of a phonological effect independent of visual similarity has been demonstrated in several naming and lexical decision experiments with Serbo-Croatian, taking advantage of the two alphabets to produce homophonous pairs without visual similarity and without sense 1 graphemic similarity (Lukatela & Turvey, 1990). Using a visual masking procedure borrowed from Humphreys et al. (1982), Lukatela and Turvey (in press, experiment 10) showed that masked pseudowords reduced lexical decision times on immediately subsequent homophonous target words. The failure of Humphreys et al. (1982) to obtain this result led them to conclude against automatic activation of pre-lexical phonology. In view of the positive outcome of Lukatela and Turvey's (1990) experiment, and the parallel results of the present experiments and those of Naish (1980) and Perfetti et al. (1988), Humphreys et al.'s (1982) conclusion should be reconsidered.

As observed in the Introduction, the data from experiments on word identification in Serbo-Croatian have motivated a network model in which phoneme processing units mediate between letter processing units and word processing units. The present results which demonstrate a phonological effect in backward masking are consistent with this model. Also consistent with the model is the demonstration in Experiment 2 of an interaction between alphabet match and phonological similarity, where alphabet mismatch yields superior identification, in the absence of phonemic similarity, than alphabet match. If a letter string containing letters unique to one of the two alphabets is presented, then letter units of the other alphabet are inhibited. An immediately following letter string that shares no graphemes/phonemes in common, will interrupt the processing of the first string. How much it does so depends, however, on the alphabet in which it is printed. If the second stimulus is printed in the other alphabet, then the letter units needed to process it will be inhibited, and more time will be needed for the second stimulus to overwrite the contents of the letter unit level. Consequently, the first stimulus will be processed further without interruption than if it had been followed by a letter string in the same alphabet.

Before concluding, an alternative view of the homophony effect needs to be addressed. Namely, the possibility that it was due to post-lexical processes. If the pseudoword mask was available to awareness, then information about it could have supplemented the information about the target at later stages rather than an earlier, pre-lexical stage. One prediction of this view is that at greater onset asynchronies between the pseudoword and the following pattern mask, the pseudoword should become more available to awareness and, consequently, the effect of homophony should increase. Although the onset asynchrony in Experiment 2 was half that in Experiment 1, the significance level of the effect of homophony was the same ($P < 0.001$). Relatedly, in Perfetti et al.'s (1988) experiments, the interaction of homophony and onset asynchrony was not significant. These observations are counter to the notion that the main effect of homophony is linked to the pseudoword mask's availableness in awareness. A further counterargument follows from the alphabet effect of Experiment 2. Under non-homophonic conditions, in which mask and target shared neither graphemes nor phonemes, pseudoword masks produced reliable influences on the correct identification of target words simply as a function of alphabet congruity. The absence of any true linguistic relation between the target and mask would seem to preclude any lexical or post-lexical interpretation of the influence of alphabet; and the particular form of the influence makes sense only in terms of a pre-lexical network with specialised inhibitory connections across alphabets of the kind described above. Given that one and the same temporal and intensity conditions gave rise to both the homophony and alphabet effects, it seems reasonable to conclude, therefore, that both are pre-lexical. The preceding observations, though counter to the post-lexical hypothesis, cannot be taken as conclusive evidence against it. Future experiments will need to include more direct evaluations of this alternative interpretation.

In summarising, we return the discussion to the model of Serbo-Croatian word recognition. The particular organisation of the units in the processing network proposed by Lukatela et al. (1989 b) expresses the peculiarities of the Serbo-Croatian orthography—its phonetic precision and its bialphabetism. These peculiarities, embodied in the pattern of connections, lead to certain predictions about word identification under backward masking: Homophonous masks should aid target identification, and the contribution of mask homophony to target identification should vary with the alphabet relation between the stimuli. Both predictions were upheld. The implication of confirming the major prediction is that word identification is mediated by phonological information. The fact that the identical outcome was obtained in the present experiments and previous experiments of the same kind in English, suggests that word identification in these different orthographies proceeds similarly by reference to phonology. The implication of confirming the secondary prediction is that a general theory of word identification cannot ignore possible variations in the functional architecture of lower-level mechanisms (e.g. letter units and phoneme units) due to variations in orthography (Turvey, Feldman, & Lukatela, 1984).

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REFERENCES

Clark, H. H. (1973). The language-as-fixed-effect fallacy: A critique of language statistics in psychological research. *Journal of Verbal Learning and Verbal Behavior*, *4*, 674–690.

Coltheart, M., Davelaar, E., Jonasson, J. T., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and performance VI*, pp. 535–555. London: Academic Press.

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.

Gernsbacher, M. A. (1984). Resolving 20 years of inconsistent interactions between lexical familiarity and orthography, concreteness, and polysemy. *Journal of Experimental Psychology: General*, *113*, 256–281.

Henderson, L. (1985). On the use of the term "grapheme". *Language and Cognitive Processes*, *1*, 135–148.

Hillinger, M. L. (1980). Priming effects with phonemically similar words: The encoding-bias hypothesis reconsidered. *Memory and Cognition*, *8*, 115–123.

Humphreys, G. W. & Evett, L. J. (1985). Are there independent lexical and nonlexical routes in word processing: An evaluation of dual route theory of reading. *The Behavioral and Brain Sciences, 8*, 689–739.

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

Lukatela, G., Feldman, L. B., Turvey, M. T., Carello, C., & Katz, L. (1989a). Context effects in bi-alphabetical word perception. *Journal of Memory and Language*, *28*, 214–236.

Lukatela, G., Savić, M., Gligorijević, B., Ognjenović, P., & Turvey, M. T. (1978b). Bi-alphabetical lexical decision. *Language and Speech*, *21*, 142–165.

Lukatela, G., Savić, M., Ognjenović, P., & Turvey, M. T. (1978a). On the relation between processing the Roman and the Cyrillic alphabets: A preliminary analysis with bialphabetical readers. *Language and Speech*, *21*, 113–141.

Lukatela, G. & Turvey, M. T. (1980). Some experiments on the Roman and Cyrillic alphabets of Serbo-Croatian. In J. F. Kavanagh & R. L. Venezsky (Eds), *Orthography, reading, and dyslexia*. pp. 227–247. Baltimore, Md.: University Park Press.

Lukatela, G. & Turvey, M. T. (1990). Phonemic similarity effects and prelexical phonology. *Memory & Cognition, 18*, 128–152.

Lukatela, G., Turvey, M. T., Feldman, L. B., Carello, C., & Katz, L. (1989b). Alphabetic priming in bi-alphabetical word perception. *Journal of Memory and Language*, *28*, 237–254.

McClelland, J. L. & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review*, *88*, 357–407.

Michaels, C. F. & Turvey, M. T. (1979). Central sources of visual masking: Indexing structures supporting seeing at a single brief glance. *Psychological Research*, *4*, 1–61.

Naish, P. (1980). The effects of graphemic and phonemic similarity between targets and masks in a backward visual masking paradigm. *Quarterly Journal of Experimental Psychology*, *32*, 57–68.

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

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

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*. Hillsdale, N.J.: Lawrence Erlbaum Associates Inc.

Van Orden, G. C. (1987). A ROSE is a ROSE: Spelling, sound and reading. *Memory and Cognition*, *15*, 181–198.

Van Orden, G. C., Johnston, J. C., & Hale, B. L. (1988). Word identification in reading proceeds from spelling to sound to meaning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*, 371–386.