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When nonwords activate semantics better than words

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Abstract

We conducted a strong test of the idea that visual word processing and the activation of a printed word's meaning proceeds at a rate scaled by the temporal evolution of a unique and stable phonological code. Using the lexical decision task, and readers fluent in the two alphabets of Serbo-Croatian, we compared the priming of a target word such as automat by the semantically related word ROBOT and by the nonword ROБOT. Whereas the Serbo-Croatian word ROBOT can support two phonological codes, /robot/ and /rovot/, the nonword ROБOT composed by illegally mixing Roman and Cyrillic letters can support only the phonological code /robot/, that corresponding to the word whose meaning is related to automat's. At a prime duration of 35 ms, the lexical decision on the target automat was facilitated by ROБOT but not by ROBOT. At a prime duration of 125 ms, the word ROBOT was the more effective prime. One consequence of phonology's leading role in visual word recognition is that a nonword can sometimes activate a given word's meaning better than the word itself. © 1998 Elsevier Science B.V. All rights reserved

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1. Introduction

Visually presented nonwords can activate semantics. The experimental demonstrations have mostly been in respect to pseudohomophones-nonword letter strings that are homophonic with words. Thus, the latency to name frog is shortened by the

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prior presentation of TODE (e.g. Lukatela and Turvey, 1994b). The implication that a letter string's phonology may play a leading role in the activation of semantics is consistent with the phonological coherence hypothesis. This hypothesis holds that the various processes leading to a pronunciation of a letter string, or a decision about its lexical status, or a judgment about its semantic category, rely on the initial achievement of a coherent phonological code. A coherent phonological code serves to mediate – in the sense of *resolve* – the competing states of time-evolving visual-semantic and phonological-semantic interactions occurring at multiple grain sizes (Van Orden et al., 1990; Stone and Van Orden, 1994; Van Orden and Goldinger, 1994).

The phonological coherence hypothesis makes a nonintuitive prediction about semantic priming that is tested in the present article, namely, under certain conditions a nonword should activate a target word's meaning better than a word semantically related to the target. The conditions are that (a) the nonword prime is homophonic with the appropriate word prime, (b) the nonword prime takes less time than the word prime to achieve phonological coherence, and (c) the time available for processing the prime is within the time scale of phonological coherence for the nonword but not necessarily for the word.

Of special relevance to the preceding conjecture are experiments in which a certain kind of letter string never encountered by a reader is shown to be a more effective (identity) prime for a familiar word than the familiar word itself (Lukatela et al., 1997). These experiments were conducted using short prime durations, brief temporal separations of prime and target and Serbo-Croatian materials. Serbo-Croatian has special advantages as a source of experimental stimuli that stem from its two partially overlapping orthographies, Roman and Cyrillic (Fig. 1), and the availability of readers who are fluent with both of them. The partial overlap is key: depending on how these characters are combined with each other and with those unique to one or

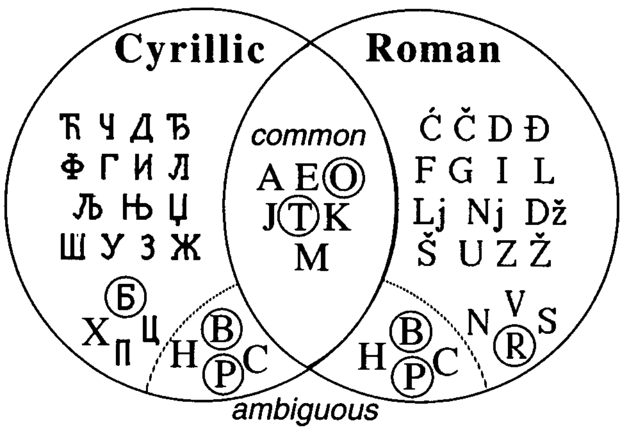

Fig. 1. The two partially overlapping alphabets of the Serbo-Croatian language. Of the letters that are shared in the upper case, the pronunciation of *common* characters is the same in Cyrillic and Roman whereas the pronunciation of *ambiguous* characters depends on alphabet. Circled letters are used in the examples of Fig. 2.

ROBOT	POBOT	ROБOT
appropriate word	ambiguous nonword	unique nonword
unique, common, and ambiguous letters	*ambiguous and common letters*	*unique and common letters*
/robot/, /rovot/	/robot/, /rovot/, /pobot/, /povot/	/robot/

Fig. 2. Three types of letter strings that share a pronunciation. A letter string can support one or more phonological interpretations depending on its mix of unique, common, and ambiguous letters. ROBOT, a legal word by its Roman reading, has an additional phonological interpretation permitted by the ambiguous letter B (/b/ in Roman; /v/ in Cyrillic). POBOT is a nonword whose two ambiguous characters, B along with P (/p/ in Roman; /r/ in Cyrillic), permit four phonological interpretations (the pronunciation that is a word requires mixing alphabets; the pure Roman, the pure Cyrillic, and the other mixed-alphabet interpretation are all nonwords). ROБOT, an illegal letter string that would not be encountered by a reader, has a single phonological interpretation, due to the unique Roman R and unique Cyrillic Б.

the other orthography (Fig. 2), letter strings can be fashioned that have one or more phonological interpretations. Research suggests that bi-alphabetical readers generate these alternative phonological codes automatically (Lukatela et al., 1989).

The preceding automaticity can be exploited in the creation of pseudohomophones that rely on a mix of alphabets in order to achieve phonological uniqueness. In the experiments of Lukatela et al. (1997), items like those in Fig. 2 were used to prime the target word robot (/robot/) in a mask–prime–mask–target presentation sequence with interstimulus intervals of 0 ms. When the prime duration was very brief (e.g. 35 ms), the mixed-alphabet phonologically unique nonword ROБOT was found, in both the naming and lexical decision tasks, to be the most effective prime. By hypothesis, the short prime–mask onset asynchrony did not allow enough time to resolve a coherent phonological code for either ROBOT (the appropriate but phonologically ambiguous word prime) or POBOT (a phonologically ambiguous nonword with one appropriate and three nonword readings). In contrast (and consonant with the hypothesis), at a longer prime duration (125 ms) all three were successful primes for robot, with ROBOT matching the effectiveness of ROБOT and both being superior to POBOT.

In the present article, we report a lexical decision experiment directed at the question: can the nonword ROБOT be a more effective semantic prime for automat (meaning 'automaton') than the appropriate word ROBOT (Fig. 3)? On the phonological coherence hypothesis, ROБOT should establish the conditions for activating the semantics of the word meaning 'robot' and, thereby, the word meaning 'automaton,' sooner than ROBOT. Consequently, at shorter time scales, but not necessarily at longer time scales, ROБOT should prime automat more effectively than ROBOT.

The manipulation of time scales to evaluate this expectation was conducted in the manner of Lukatela et al. (1997); that is, in the context of a mask–prime–mask–target sequence presented binocularly. A major challenge with binocularly viewed

	Phonologically ambiguous word	Phonologically ambiguous pseudoword	Phonologically unique pseudoword	Common baseline prime	Target word
	1	2	3	4	
Test primes	ROBOT	POBOT	ROБOT	XXXXX	automat *Roman*
	5	6	7	8	
Individualized control primes	BARON	BAPOH	БARON	XXXXX	
	1	2	3	4	
Test primes	XAPEM	HAPEM	XAREM	XXXXX	жене *Cyrillic*
	5	6	7	8	
Individualized control primes	БETOH	BETOH	БETON	XXXXX	

Fig. 3. Sample primes for phonologically unique target words in the two alphabets. The prime-target pairs (prime in upper case, target in lower case) were constructed such that each of the three kinds of theoretically important or test primes had its own individualized control which matched the test prime in number of unique, ambiguous, and common letters; in length and frequency (defined by the appropriate prime); and differed from the test prime in visual form as far as the preceding two constraints permitted. For the Roman targets, the appropriate prime was a word by its Roman reading; for the Cyrillic targets, the appropriate prime was a word by its Cyrillic reading. (Numbers refer to types of stimuli.)

stimuli at extremely short time scales is the separation of prime and target processing. It is desirable to minimize the energy-based integration of prime and target that occurs peripherally and the pattern-based integration that occurs centrally (e.g. Michaels and Turvey, 1979). The post-prime mask is intended to serve these purposes. Further, in the comparison of short and long time scales under the preceding minimization criterion, a major challenge is to equate for the peripheral contamination of the prime by the post-prime mask. This challenge can best be met by equating the prime and post-prime mask in energy. In binocular viewing, briefly separated stimuli interact peripherally according to their respective energies as given by the product of duration and intensity (e.g. Turvey, 1973; Michaels and Turvey, 1979). In preview of the experimental procedure, semantic priming of lexical decisions on automat by ROBOT, POBOT, and ROБOT was examined at prime durations (and post-prime mask durations) of 35 ms and 125 ms.

Our experiment addressed an additional but related issue, namely, the basis for the activation of semantics by nonhomophonic nonwords. Experiments with English materials suggest that such an effect (e.g. TORD priming frog) is small, attaining significance at very short prime durations in the lexical decision task where proper semantic priming (e.g. by TOAD) is on the order of 30 ms (Bourassa and Besner, 1998) but not in the rapid naming task where proper semantic priming is only on the order of 10 ms (Lukatela and Turvey, 1994a). The finding that nonhomophonic nonwords can produce semantic priming at extremely short prime durations is potentially approachable through a number of models of visual word recognition that assign a leading role to orthographic rather than phonological patterns (e.g. Coltheart et al., 1993; Masson, 1995). For example, in the dual-route cascade model

(Coltheart et al., 1993), the near-maximal letter overlap between the nonwords ROБOT and POBOT and the word ROBOT might suffice to partially activate robot's representation in the orthographic lexicon and, in turn, its semantic representation. Assuming connections among semantic relatives, some priming of automaton by both ROБOT and POBOT (though less than that by ROBOT) would be expected. Such an orthographic-based account, however, would not predict better semantic priming by ROБOT under any circumstances. Within the dual-route cascade model, this prediction can only be approached by letting the phonological (nonlexical) route lead the visual (lexical) route; that is, by reversing the temporal ordering that characterizes the model's normal operating mode.

2. Stimuli

To determine the semantically related pairs (such as ROBOT–automat), an original set of 96 words was given to 30 randomly selected students at the Gymnasium with the request that they generate, for each word, five corresponding related words. These generated words were then judged, in each case, for their degree of relation to the original word by another group of 30 randomly selected students. The generated response receiving the highest average ranking defined the target for the original (prime) word. None of the students in either of the two preceding groups involved in determining the semantic pairs participated in the experiment proper.

The prime–target pairs (prime in upper case, target in lower case) were constructed such that each of the three kinds of theoretically important or test primes had its own individualized control which matched the test prime in length and frequency (defined by the appropriate prime) and differed from the test prime in visual form as far as the preceding two constraints permitted (see Lukatela and Turvey, 1994a; Lukatela et al., 1997). There were eight types of stimuli (see Fig. 3). Sets 1–3 were the test primes. The primes in Sets 5–7 were the individualized control primes (see Fig. 3). The primes in Sets 4 and 8 consisted simply of XXXXX. With this design, the test primes could be compared with respect to the degree that they primed differently from their individualized controls and they could also be compared with each other and with a common prime (XXXXX).

3. Method

One hundred and twelve senior students (16–18 years old) at the 14th Gymnasium in Belgrade participated. There were two groups of 56 participants defined by the two prime durations. Within each group, participants were assigned randomly to one of eight subgroups to allow seven participants per subgroup. All participants were fluent readers in both the Roman and Cyrillic alphabets.

Each participant received 12 different instances of each of the eight types of prime–target pairs for a total of 96 pairs. The major constraint was that no participant saw any prime (other than XXXXX) or target more than once. To satisfy this constraint, eight counterbalanced experimental lists of 96 pairs were prepared, one list for each of the eight groups of participants. In addition, each participant in each group saw 48 stimulus pairs consisting of a word prime and a nonword target. In each word–nonword pair the prime and target's source word were necessarily two different lexical entries. The experimental sequence of 144 prime–target pairs was preceded by a practice sequence of 38 prime–target pairs. Participants, run one at a time, sat in front of the computer CRT in a well-lit room. Each trial consisted of an auditory warning signal followed by a sequence of visual presentations: a pattern mask of 500 ms duration, a prime of 35 ms and a second pattern mask of 35 ms, or a prime of 125 ms duration and a second pattern mask of 125 ms duration, and finally a target of 400 ms duration. All interstimulus intervals were zero (ISI = 0).

The participant performed a rapid lexical decision on the target stimulus of each stimulus pair. The participant used simultaneously both hands placed on two telegraph keys. One telegraph key was pressed with both forefingers ('YES'), and the second telegraph key was pressed with both thumbs ('NO').

4. Results

For each participant, latencies to word targets less than 100 ms and more than 1400 ms were excluded (resulting in less than a 0.5% truncation, satisfying the criterion of Ulrich and Miller, 1994). Mean latencies and error rates are summarized in Table 1. The variety of primes was such that the degree of priming by the test primes could be compared with each other, with their individualized controls, and with a common prime (XXXXX). The amount of priming for the test primes relative to their individualized controls is shown in Fig. 4. Only ROБOT produced reliable priming at prime duration = 35 ms; both ROBOT and ROБOT produced reliable priming at prime duration = 125 ms. An analysis of variance (ANOVA) focusing on just the appropriate, semantically-related primes (e.g. ROBOT and its control BARON) and the unique nonwords (e.g. ROБOT and its control БARON) revealed an interaction between prime type, relatedness, and prime duration, $F1(1,110) = 16.03, P < 0.001$; $F2(1,94) = 5.77, P < 0.05$ (where $F1$ and $F2$ refer to analyses by subjects and items, respectively). The effectiveness of appropriate primes relative to their individualized controls improved dramatically with prime duration whereas the effectiveness of phonologically unique nonword primes relative to their individualized controls declined with prime duration. The degree of priming induced by ROBOT, POBOT, and ROБOT relative to the common control stimulus XXXXX is shown in Fig. 5. The results were in essential agreement with the preceding: only ROБOT produced reliable priming at prime duration = 35 ms, whereas only ROBOT produced reliable priming at prime duration = 125 ms.

The overall lexical decision times were consistent with these priming differences: An ANOVA focusing on the comparison of the appropriate word primes and the unique nonword primes revealed that target latencies following ROBOT were

Table 1
Mean lexical decision latencies *L* (in ms) and error rates *ER* (in %), with standard deviations by participants and items, at two prime durations as a function of test primes and their individualized controls for appropriate word, nonword ambiguous, nonword unique, and neutral baseline primes

Prime type							
Appropriate word		Phonologically ambiguous nonword		Phonologically unique nonword		Neutral baseline	
35 ms							
Test primes							
(ROBOT)		(РОВОТ)		(ROБOT)		(XXXXX)	
L	*ER*	*L*	*ER*	*L*	*ER*	*L*	*ER*
582[a]	5.21	589	5.51	575	4.02	587	8.78
60[b]	9.53	62	9.34	61	8.06	62	10.41
53[c]	11.01	57	10.48	48	9.15	48	14.27
Individualized controls							
(BARON)		(ВАРОН)		(БARON)		(XXXXX)	
L	*ER*	*L*	*ER*	*L*	*ER*	*L*	*ER*
583	6.85	592	6.70	594	6.25	583	7.00
61	10.82	65	10.64	61	10.71	57	11.08
46	13.40	51	12.17	58	23.65	53	12.28
125 ms							
Test primes							
(ROBOT)		(РОВОТ)		(ROБOT)		(XXXXX)	
L	*ER*	*L*	*ER*	*L*	*ER*	*L*	*ER*
583	7.44	607	8.04	600	6.10	610	8.93
69	10.87	70	11.88	70	10.52	73	11.74
70	14.66	73	13.28	62	11.17	67	14.35
Individualized controls							
(BARON)		(ВАРОН)		(БARON)		(XXXXX)	
L	*ER*	*L*	*ER*	*L*	*ER*	*L*	*ER*
616	6.70	615	6.55	611	9.38	613	7.89
70	10.35	72	10.63	74	11.41	77	11.10
70	15.17	70	12.32	77	16.64	76	15.57

[a]Mean.
[b]Standard deviation by subjects.
[c]Standard deviation by items.

slower than latencies following ROБOT at 35 ms but the reverse was true at 125 ms, $F1(1,110) = 12.17$, $P < 0.001$; $F2(1,94) = 4.68$, $P < 0.05$.

5. Discussion

Our experiment took advantage of special features of the Serbo-Croatian writing system to create a strong test of the idea that visual word processing and the activation of a word's meaning proceeds at a rate scaled by the temporal evolution of a unique and stable phonological code (Van Orden et al., 1990; Van Orden and

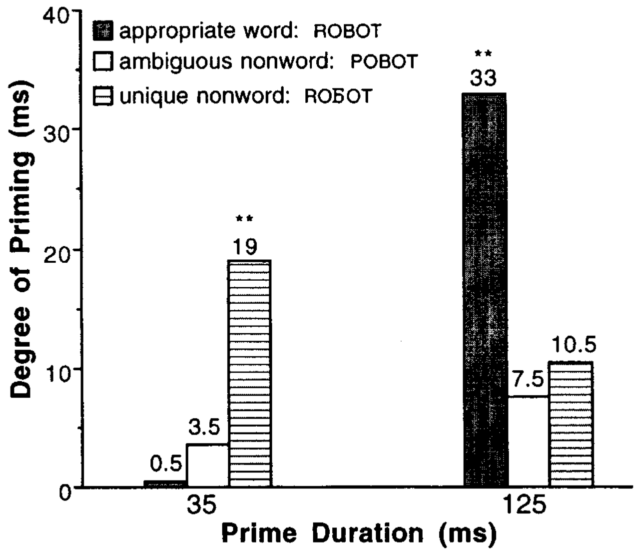

Fig. 4. The amount of associative priming for each test prime compared to its individualized control prime. Significant planned comparisons (by subjects and items) relative to the controls are indicated by **. Left: for prime duration = 35 ms, the partial interactions indicated that ROБOT's 19 ms of priming exceeded the 0.5 ms by ROBOT and the 3.5 ms by POBOT. Right: at prime duration = 125 ms, the partial interactions indicated that the 33 ms of priming by ROBOT exceeded the 7.5 ms by POBOT. There were no reliable effects in the error analyses.

Goldinger, 1994). If the time to achieve a coherent phonological representation dictates the time course of stabilizing the other codes relevant to word recognition, then the phonologically unambiguous (and visually anomalous) nonword ROБOT should have an advantage at short prime durations over the phonologically ambiguous word ROBOT. By the same token, the visually similar nonword POBOT, with its four phonological forms, should be at a disadvantage. The experiment showed that (a) the unique nonword, which is unlikely to have been seen by the reader of Serbo-Croatian, was a more effective prime at the prime duration of 35 ms than the appropriate but phonologically ambiguous word, which has been seen commonly; (b) the appropriate but phonologically ambiguous word became the more effective prime at the prime duration of 125 ms; and (c) the ambiguous nonword was effective at neither prime duration.

The failure of POBOT to prime raises the possibility that demonstrations in English of semantic priming by nonhomophonic nonwords that differ from a real word by a single letter (Bourassa and Besner, 1998) may be dependent on the prime's phonological uniqueness. The fact that ROБOT's effectiveness as a semantic prime declined with an increase in prime duration suggests a clean-up process tied to the letter string's orthographic pattern. Roughly speaking, the implicit realization that 'This is not the spelling of any word' – a realization that grows as more time elapses before the onset of the post-prime mask (e.g. Paap et al., 1982) – deactivates the semantic pattern excited by ROБOT's phonology.

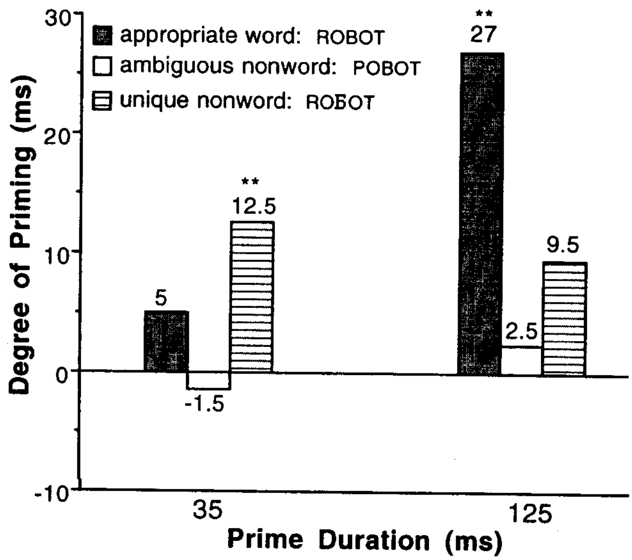

Fig. 5. The amount of associative priming for each test prime compared to a neutral XXXXX baseline prime. Significant planned comparisons (by subjects and items) relative to XXXXX are indicated by **. Left: at prime duration = 35 ms, the partial interactions indicated that ROБOT's 12.5 ms of priming exceeded the − 1.5 ms by POBOT. Right: at prime duration = 125 ms, the partial interactions indicated that the 27 ms of priming by ROBOT exceeded the 0.5 ms by POBOT and was close to reliable (being marginal by items) over ROБOT's 9.5 ms. There were no reliable effects in the error analyses.

Our results, therefore, are consistent with a major claim of the phonological coherence hypothesis: the rate at which a printed word's meaning is activated in the mind of a fluent reader is constrained primarily by the time it takes to achieve a stable phonological code. A close companion of the phonological coherence hypothesis is the view that reading is a phonologically analytic and generative process based in the mechanisms by which speech is perceived and produced (Liberman, 1995). Accordingly, evidence obtained in favor of the phonological coherence hypothesis (as supplied here) lends support to the idea that awareness of the phonology of words, spoken and written, is a key factor in achieving reading fluency (Brady and Shankweiler, 1991).

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