EUROPEAN JOURNAL OF COGNITIVE PSYCHOLOGY, 1999, *11* (1), 1–16

Effects of Frequency and Phonological Ambiguity on Naming Serbo-Croatian Words

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The Serbo-Croatian word corresponding to the English noun *wind* is written BETAP in the Cyrillic alphabet and VETAR in the Roman alphabet. Typically, bi-alphabetic readers name BETAP more slowly and with more errors than VETAR. BETAP is phonologically ambiguous because B and P specify the phonemes /b/ and /p/ in Roman and /v/ and /r/ in Cyrillic. We conducted an experiment to determine whether this naming difference between phonologically ambiguous and phonologically unique words depends on word frequency. The naming difference was of the same magnitude for high- and low-frequency words when the stimulus presentation was prolonged; with very brief presentation, the naming difference remained but frequency influenced only the phonologically ambiguous words. The results are discussed with respect to a single-route account of naming in which (a) a lower orthographic–phonological network, shaped by asymptotic learning, generates automatically all phonological patterns specified by a letter string, and (b) a higher phonological–semantic network, shaped by individual word frequencies, enhances phonological pattern selection through adaptive resonance.

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This research was supported in part by National Institute of Child Health and Human Development Grant HD-01994 to the Haskins Laboratories. The authors would like to acknowledge the conceptual contributions of Guy Van Orden.

Because of the use of two, partially overlapping alphabets (Roman and Cyrillic), and because of the one letter–one phoneme principle for both alphabets, it is possible to construct letter strings in Serbo-Croatian that can be read legally in more than one way. 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 nonword. Read with a mixture of the two sets of correspondences, Cyrillic and Roman, leads to the pronunciations /vetap/ and /betar/, which are also nonwords. 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 naming, the latencies for BETAP, and for letter strings like it, are considerably longer than the latencies for VETAR, and for letter strings like it, even though the two letter strings are equal in frequency, syllabic structure, number of letters and meaning. (The same contrast prevails when the Cyrillic form is unique and the Roman counterpart is ambiguous.) This contrast is the phonological ambiguity effect (see Lukatela & Turvey, 1990, 1991, for reviews). Intuitively, the resolution of a (unique) phonological code to support correct naming takes longer for BETAP than for VETAR (Lukatela et al., 1989b).

Let us consider BETAP in more detail. The goal is to appreciate how the coding of BETAP relative to that of VETAR is different from the coding of exceptional English words relative to that of regular English words. BETAP can support four phonological codes (B would automatically activate /b/ and /v/, and P would automatically activate /p/ and /r/). The mapping from the orthographic structure of BETAP to the corresponding phonological structure violates a single-valued mapping at the subword (subsymbolic) level. Unlike a frequently occurring English exception word, however, this phonological noise cannot be eradicated through asymptotic learning. The frequency at which the subword connections are reinforced outweighs by far the frequency of BETAP. Thus, in the bi-alphabetic reader, B will connect to /b/ almost as often as it does to /v/, and the connections specific to the adjacency structure of BETAP will not be able to outweigh these generic subsymbolic correspondences. Said differently, the phonological noise in BETAP is of a different kind than that in DO, our example from above. In BETAP it arises from the *alphabetically consistent* phonological coding of the orthographic subsymbols B_1 and P_5; in DO it arises from the *alphabetically inconsistent* phonological coding of the orthographic subsymbol O_2. In summary, asymptotic learning is thwarted by the phonological consistency of the Serbo-

were fluent readers of both alphabets. As natives of Serbia, they will have learned Cyrillic first. Although the first learned script has residual precedence in some tasks (Lukatela et al., 1978), such an advantage for naming latency disappears by the fifth grade (Feldman, 1983).

According to his or her order of appearance at the laboratory, each student was assigned to one of four subgroups of eight subjects, each with two subgroups viewing stimuli of 40 msec duration and two subgroups viewing stimuli of 500 msec duration.

Materials

Two sets of words were assembled. The first set consisted of 36 low-frequency (LF) and 36 high-frequency (HF) phonologically unambiguous Serbo-Croatian words that were used as target stimuli. All words were nouns in the nominative singular case. One-half of these stimuli were written in the Cyrillic alphabet and the other half were written in the Roman alphabet. The average frequency of occurrence of the low-frequency words was 7 (standard deviation of 5) and that of the high-frequency words 273 (standard deviation of 38), based on Lukić's (1981) count of a corpus of 1.5 million words. Importantly, all words in the present experiment had the standard Serbo-Croatian prosodic pattern with the stress on the first syllable. Most of the words were 4–5 letters in length and were bi-syllabic. The remainder were mono- or tri-syllabic. The second set consisted of 72 phonologically ambiguous words which were generated from the first set by transcribing each unambiguous word (e.g. VETAR /vetar/ = the wind, by Roman reading) into the other alphabet (e.g. ВЕТАР /vetar/ = the wind, by Cyrillic reading). All 72 phonologically ambiguous letter strings were orthographically and phonologically legal by both readings and, as such, easily pronounceable in both readings. Consequently, all experimental letter strings in the present experiment were evenly divided into phonologically unambiguous and phonologically ambiguous letter strings and, additionally, all letter strings were evenly divided into Roman and Cyrillic scripts. One-half of the Cyrillic phonologically ambiguous words and one-half of the Roman phonologically ambiguous words made up the set of high-frequency phonologically ambiguous words. The other half of each made up the set of low-frequency phonologically ambiguous words. It should be underscored that the set of words satisfying the experimental criteria is close to exhaustive.

Design

Sixteen subjects were assigned to each of two target durations, 40 and 500 msec. Each set of stimuli was evenly divided between two counterbalanced lists; within a target duration, one subgroup of eight subjects

latency was longer than 1200 msec, a message appeared on the screen requesting the subject to name more quickly. All latencies, including those longer than 1200 msec, were stored in the computer's memory.

RESULTS

The results for the two exposure durations are shown in Fig. 1. A 2 (phonology) × 2 (frequency) × 2 (duration) analysis of variance (ANOVA) was conducted on latencies. The ANOVA was restricted to

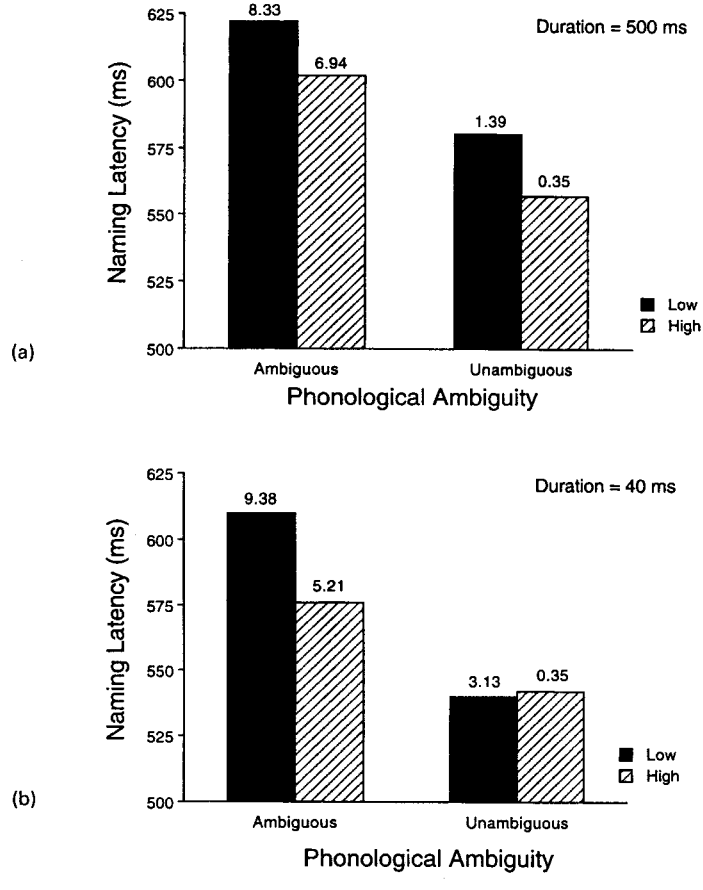

FIG. 1. Naming latency (msec) as a function of phonological ambiguity and frequency for stimulus durations of (a) 500 msec and (b) 40 msec. Corresponding error rates (in %) are shown above each bar.

The present experimental outcome can be interpreted within the processing model advanced by Lukatela et al. (1989b) and the analogous models of Seidenberg and McClelland (1989), Van Orden and Goldinger (1994) and Plaut, McClelland, Seidenberg and Patterson (1996). All Serbo-Croatian letter strings (words and nonwords) are processed through the same network of processing units. The network consists essentially of an orthographic units–phonological units matrix of connections and a phonological units–lexical units matrix of connections. The two matrices are linked through the level of phonological processing units. By means of the orthographic–phonological matrix, each word is assigned a phonological interpretation befitting the structure of its orthography. In response to BETAP-type words, the orthographic–phonological matrix will generate four phonological representations; in response to VETAR-type words, it will generate one phonological representation that conforms exactly to the structure of /vetar/. In either case, the evolving phonological representation participates in the phonological–lexical matrix. By means of this matrix, and the mechanism of resonant equilibration, ambiguous phonology is resolved, non-standard stress is assigned if lexically prescribed, and word frequency impresses itself upon the time course of naming.

One particular feature of the foregoing model deserves additional comment. The asymptotic learning hypothesis expresses the idea that the connections coding high-frequency words are updated at a rate that reduces or eliminates the noise in phonological codings. A learning algorithm such as the generalised delta-rule expresses a strong form of this hypothesis. Given enough encounters with high-frequency words, ambiguity arising from inconsistent cross-talk would be eliminated. By the strong version of the asymptotic learning hypothesis, therefore, BETAP-type words should become indistinguishable in their coding from their VETAR-type partners. Neither should engender ambiguity (noise) in the orthographic–phonological network that encodes them. The fact that the phonological ambiguity effect persisted for high-frequency words (e.g. BETAP *vs* VETAR) suggests that the strong version of the asymptotic learning hypothesis should be rejected. The weaker version is consistent with Hebbian-type learning algorithms that reduce but do not eliminate the effects of inconsistent cross-talk.

The preceding model was developed to address a large body of data on recognising and pronouncing Serbo-Croatian words (for reviews, see Carello, Turvey, & Lukatela, 1992; Lukatela & Turvey, 1990, 1991; Lukatela et al., 1989b). Most research on recognising and pronouncing words has been motivated by a theory different in kind from that advocated for Serbo-Croatian, namely the dual process theory (Coltheart, 1978). Contemporary variants of this theory have been advanced by

Because of the consistency of the Serbo-Croatian orthography, it can be argued that all non-lexical horses are nearly as fast as the fastest lexical horses. High-frequency VETAR-type and high-frequency BETAP-type words (such as VETAR and BETAP themselves) will have fast horses on both tracks. Suppose that they are so closely matched that the result is a photo-finish. (Paap et al. assume that the track stewards are conservative in their assessment of clear winners, usually declaring close races a photo-finish.) In the case of VETAR, there is one horse on each track with both horses delivering the same name, so the photo finish is easily resolved. In the case of BETAP, there is one horse on the lexical track and four horses on the non-lexical track. The decision on the photo-finish is delayed as the stewards must contend with several names before resolving the conflict in favour of the name provided by the lexical horse (Paap et al., 1992). The upshot is that high-frequency unambiguous words will be named faster than their ambiguous counterparts. With respect to low-frequency unambiguous words, the non-lexical horse arrives far ahead of the lexical horse and delivers a unique pronunciation. The advantage for the non-lexical horse is the same for low-frequency ambiguous words as it is for high-frequency ambiguous words, but now the stewards must wait for the slower lexical horse in order to arrive at a unique pronunciation. In sum, Paap and co-workers' theory predicts that, under normal viewing conditions, the phonological ambiguity effect should occur for both high- and low-frequency words.

What of the frequency effect itself? The requirement of a photo-finish to obtain a phonological ambiguity effect with high-frequency words rules out a high- versus low-frequency difference for unambiguous words. According to the hypothesis of Paap et al., for both high- and low-frequency unambiguous words, the latency is tied to the non-lexical horse which runs at the same speed in both cases. With high-frequency unambiguous words, the non-lexical horse is in a tie with the lexical horse as far as the stewards are concerned; with low-frequency unambiguous words, the non-lexical horse is the only winner. With respect to ambiguous words, a high- versus low-frequency difference would follow from the slower running of the lexical horse in the low-frequency case and the fact that the stewards cannot reach a decision on ambiguous words until the lexical horse arrives. In sum, Paap and co-workers' theory predicts that, under normal viewing conditions, a frequency effect should only be found for ambiguous words. With a 500 msec exposure, the present experiment revealed identical and significant frequency effects for both VETAR-type and BETAP-type words. If the photo-finish assumption is dropped, however, and the lexical horse is a clear winner for high-frequency words, then a high- versus low-frequency difference would be expected for unambiguous words but a phonological ambiguity

needed to resolve a unique pronunciation for phonologically ambiguous Serbo-Croatian words and to resolve the stress pattern of all Serbo-Croatian words, whether ambiguous or unique (Carello, Lukatela, & Turvey, 1988, 1994; Carello et al., 1992; Lukatela et al., 1989a; Lukatela & Turvey, 1990). These equilibrating processes can be expected to take longer for ambiguous words (e.g. BETAP) than for their unique counterparts (VETAR), and longer for low-frequency words than for high-frequency words. In Grossberg and Stone's (1986) formulation, the list representations of high-frequency words make larger and faster contributions to the top-down processes in the early phases of resonant equilibration. Consequently, the higher the frequency of the presented word, the sooner the network resonates. The upshot of the preceding is that, under ordinary viewing conditions (approximated by the 500 msec exposure), and with ample opportunity for phonological–semantic resonance to occur, the word-frequency effect should be observed for both BETAP-type and VETAR-type words. Via coupling, the equilibrating process in the phonological–semantic network facilitates that in the orthographic–phonological network, and vice versa. In both networks, the time course of resonant equilibration is governed by the noise in the initial encoding; the greater the noise, the further the network from the eventual equilibrium state. It is assumed that the mapping from orthography to phonology is more nearly invariant than the mapping from phonology to semantics, with the consequence of a less noisy initial encoding and a faster equilibration in the orthographic–phonological network (Carello et al., 1992; Van Orden et al., 1990; Van Orden & Goldinger, 1994).

Focusing on the experimental consequences of the 40 msec exposure, the preceding suggests that, if stress is of the standard form and identified to the subject as such (see Lukatela & Turvey, 1990), then VETAR-type words can, in principle, be named uniquely in the absence of the phonological–lexical network but BETAP-type words can be named uniquely only through the phonological–lexical network. A sharp contrast between the effects of frequency on naming VETAR-type words and naming BETAP-type words might be expected, therefore, if experimental conditions invited the naming response as soon as the code relevant to pronunciation could be stabilised and before the equilibrating process in the phonological–semantic network ran its course. Specifically, naming VETAR-type words would become frequency-independent but naming BETAP-type words would remain frequency-dependent. If the 40 msec presentation condition satisfied the preceding condition (that is, inviting naming before phonological–semantic equilibration), for whatever reason, then a pattern of results similar to that in Fig. 1b would be manifest.

By way of summary, we repeat that the present research was directed at the phonological ambiguity effect in Serbo-Croatian and the question

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