Research Report

Sequential Effects of Phonological Priming in Visual Word Recognition

Manuel Carreiras,[1] Ludovic Ferrand,[2] Jonathan Grainger,[3] and Manuel Perea[4]

[1]Universidad de La Laguna, Tenerife, Spain; [2]CNRS and Université René Descartes, Paris, France; [3]LPC-CNRS, Université de Provence, Marseille, France; and [4]Universitat de València, Valencia, Spain

ABSTRACT—***Two masked priming experiments were conducted to examine phonological priming of bisyllabic words in French, and in particular, whether it operates sequentially or in parallel. Bisyllabic target words were primed by pseudowords that shared either the first or the second phonological syllable of the target. Overlap of the first syllable only—not the second—produced facilitation in both the lexical decision and the naming tasks. These findings suggest that, for polysyllabic words, phonological codes are computed sequentially during silent reading and reading aloud.***

A large body of research in cognitive psychology has been devoted to studying the role played by phonological information in silent reading. Many of these studies have used monosyllabic pseudohomophones as primes for monosyllabic targets, thus maximizing phonological overlap between primes and targets (e.g., Drieghe & Brysbaert, 2002; Ferrand & Grainger, 1992, 1993, 1994; Frost, Ahissar, Gottesman, & Tayeb, 2003; Lukatela & Turvey, 1990; Ziegler, Ferrand, Jacobs, Rey, & Grainger, 2000). More recently, there is evidence of phonological priming effects with only partial phonological overlap in polysyllabic words (faster response to *CANAL* after *conal* than after *cinal*; Pollatsek, Perea, & Carreiras, in press).

The study of phonological effects when there is only partial phonological overlap between primes and targets raises a number of issues, one of them being whether phonological codes are computed sequentially from beginning to end or in parallel. Although most of the literature on masked phonological priming has assumed that phonological coding occurs in parallel for all letters of the input, some theories, such as the dual-route cascaded (DRC) model (see Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), predict that position of overlap may have an influence on phonological priming. In the DRC model, nonlexical letter-to-sound conversion procedures operate serially across the input string. Accordingly, phonological priming effects should be more evident when prime stimuli share phonology with the beginnings, rather than the ends, of target words. Although this appears to be likely for reading aloud (because articulatory output necessarily requires serial order), the key question is whether the same sequential computation applies when no articulatory output is required (i.e., silent reading, lexical decision).

Furthermore, one important prediction from strong phonological accounts of visual word recognition (see Frost, 1998) is that phonological priming should be observed when there is little graphemic overlap (see Rastle & Brysbaert, 2004). If the mandatory phonological codes are computed early in the process of visual word recognition (Frost et al., 2003), priming should be greater the more phonological primes are graphemically different from the target words (e.g., greater priming for *yuice-use* than for *douke-use*). In the present study, prime stimuli shared only a single letter with target stimuli.

Thus, the present experiments address two key issues regarding the role of phonology in reading polysyllabic words: (a) whether it is possible to obtain phonological priming in a lexical decision task when the overlap between primes and targets is partial (one out of two phonological syllables) and when orthographic overlap is minimal (e.g., whether *fomie* primes *FAUCON*), and (b) whether phonological codes are computed sequentially or in parallel (i.e., whether or not the two syllables of bisyllabic words carry equal weight). To examine these questions, we used bisyllabic French target words (e.g., *FAU-CON*), each

Address correspondence to Manuel Carreiras, Departamento de Psicología Cognitiva, Universidad de La Laguna, 38205-Tenerife, Spain; e-mail: mcarreir@ull.es.

of which was preceded by a briefly presented nonword prime that shared the target's first phonological syllable (*fo-mie*), a briefly presented orthographic control nonword that shared only the first phoneme (and grapheme) of the target's first syllable (*fé-mie*), or a briefly presented unrelated control nonword (*pé-mie*). We also used bisyllabic target words (e.g., *GA-TEAU*) that were preceded by nonword primes that shared the target's second phonological syllable (*re-tôt*), orthographic control nonwords that shared only the first phoneme (and grapheme) of the second syllable (*re-tin*), or unrelated control nonwords (*re-din*).

EXPERIMENT 1: LEXICAL DECISION

Method

Participants

Thirty psychology students at René Descartes University, France, took part in the experiment for course credit. They were tested individually in a quiet room. All participants reported being native French speakers, with normal or corrected-to-normal vision.

Stimuli and Design

A set of 120 French words and 120 nonwords served as target items in Experiment 1. All stimuli were bisyllabic and were 5 to 8 letters long. Half of the target words were primed on the first syllable (*first-syllable targets*), the other half being primed on the second syllable (*second-syllable targets*). First-syllable targets and second-syllable targets were matched for length in letters (5.86 and 5.85, respectively) and frequency (35 and 31 occurrences per million, respectively; New, Pallier, Brysbaert, & Ferrand, in press).

Each type of target was preceded by three types of nonword primes (syllable primes, single-phoneme primes, and unrelated primes). First-syllable targets (such as *FAUCON*, "hawk") were preceded by (a) nonword primes with the same first phonological syllable (but not orthographic syllable) as the target (e.g., *fomie-FAUCON*), (b) nonword primes sharing the first phoneme (and grapheme) only with the target (single-phoneme primes; e.g., *fémie-FAUCON*), and (c) nonword primes unrelated (both orthographically and phonologically) to the target (e.g., *pémie-FAUCON*). Second-syllable targets (such as *GATEAU*, "cake") were preceded by (a) nonword primes with the same second phonological syllable as the target (e.g., *retôt-GATEAU*), (b) nonword primes sharing the first phoneme (and grapheme) of the second syllable only with the target (single-phoneme primes; e.g., *retin-GATEAU*), and (c) nonword primes unrelated (both orthographically and phonologically) to the target (e.g., *redin-GATEAU*). It should be noted that the single-phoneme primes also served as an orthographic control for the syllable primes, because they had the same level of orthographic overlap.

Priming condition was crossed with target type. Targets and primes were rotated across the priming conditions across three groups of participants such that no participant saw any single prime or target more than once, but each participant received all three priming conditions. Every participant saw 120 pairs of nonword primes with word targets (20 pairs in each condition) and 120 pairs of nonword primes with nonword targets. The participants were presented with 20 practice trials before the experiment proper.

Procedure

The experiment was run using DMDX (Forster & Forster, 2003). Each trial began with a forward mask consisting of a row of 11 pound signs (###########) together with two vertical lines (i.e., one above and one beneath the center of the forward mask). The mask was presented for 500 ms and followed immediately by the prime stimulus. The prime was presented in lowercase 12-point Courier New font and stayed on the screen for 59 ms. The uppercase target stimulus appeared immediately afterward, in the same font and point size. Both prime and target were presented in the same location as the forward mask, at the center of the screen. The target remained on the screen until the participant responded.

Participants were instructed to indicate as rapidly and as accurately as possible whether or not the uppercase letter string was a French word. The existence of a prime stimulus was not mentioned. The participants responded using response buttons on a Logitech Wingman Gamepad. They answered "yes" by pressing the button corresponding to the forefinger of the preferred hand and "no" by pressing the button corresponding to the forefinger of the nonpreferred hand. The intertrial interval was 1 s. Stimulus presentation was randomized, with a different order for each participant.

Results

Mean lexical decision latencies and percentages of errors for the word targets are given in Table 1. Planned comparisons on the reaction times (RTs) and error rates assessed syllable priming (phonological-syllable prime vs. unrelated prime and phonological-syllable prime vs. single-phoneme prime) and phoneme priming (single-phoneme prime vs. unrelated prime) for both first-syllable targets and second-syllable targets. F values are reported by subjects (F_1) and items (F_2). Prior to the RT analyses, RTs higher than 1,500 ms (less than 2% of the data) were removed.

First-Syllable Targets

Planned comparisons showed that word targets preceded by a phonological-syllable prime were responded to 15 ms faster than word targets preceded by an unrelated prime (i.e., effect of syllabic priming; see Table 1), $F_1(1, 27) = 8.52$, $p < .01$, $\eta^2 = .24$, and $F_2(1, 57) = 15.24$, $p < .001$, $\eta^2 = .21$. In addition, word targets preceded by a phonological-syllable prime were re-

TABLE 1

Reaction Time (in Milliseconds) and Percentage Errors on Target Words as a Function of Type of Target, Priming Condition, and Task

	Task			
	Lexical decision		Naming	
Priming condition	Reaction time	Errors	Reaction time	Errors
First-syllable targets				
First phonological syllable (e.g., *fomie-FAUCON*)	603 (57)	5.16	529 (42)	0.0
Initial phoneme of first syllable (e.g., *fémie-FAUCON*)	617 (60)	6.33	539 (43)	0.33
Unrelated (e.g., *pémie-FAUCON*)	618 (66)	5.66	556 (44)	0.33
Syllable priming	+15		+27	
Phoneme priming	+1		+17	
Second-syllable targets				
Second phonological syllable (e.g., *retôt-GATEAU*)	620 (67)	6.83	554 (43)	0.33
Initial phoneme of second syllable (e.g., *retin-GATEAU*)	620 (63)	6.33	553 (45)	0.33
Unrelated (e.g., *redin-GATEAU*)	627 (65)	7.5	553 (41)	0.5
Syllable priming	+7		−1	
Phoneme priming	+7		0	

Note. For reaction times, standard deviations are given in parentheses.

sponded to 14 ms faster than word targets preceded by a single-phoneme prime, $F_1(1, 27) = 4.52$, $p < .05$, $\eta^2 = .14$, and $F_2(1, 57) = 16.56$, $p < .001$, $\eta^2 = .23$. The 1-ms difference between word targets preceded by a single-phoneme prime and word targets preceded by an unrelated prime (i.e., phoneme priming) was not significant, $F_1(1, 27) < 1$ and $F_2(1, 57) < 1$. Planned comparisons on the error rates showed no significant effects (all Fs < 1).

Second-Syllable Targets

None of the planned comparisons involving the second-syllable targets approached significance (all Fs < 1).

EXPERIMENT 2: NAMING

Method

Participants

Thirty psychology students at René Descartes University took part in the experiment for course credit. All participants reported being native French speakers, with normal or corrected-to-normal vision. None of them had participated in Experiment 1.

Stimuli and Design

The stimuli and design were the same as in Experiment 1, except that the task was naming (instead of lexical decision) and only word targets were presented.

Procedure

The procedure was the same as in Experiment 1, except that the participants' task was to read aloud the uppercase words as quickly and as accurately as possible. Naming latencies were measured and recorded by DMDX via a microphone.

Results

Mean naming latencies and percentages of errors are given in Table 1. The statistical analyses were parallel to those in Experiment 1, except that only RTs were considered given that error rates were negligible (mean of 0.3% across all subjects). RTs less than 300 ms or longer than 1,000 ms (because of hesitation, failure of the voice key, stuttering, etc.) were excluded from the RT analyses, leading to 1.5% of the data being rejected.

First-Syllable Targets

Planned comparisons showed that word targets preceded by a phonological-syllable prime were named 27 ms faster than word targets preceded by unrelated primes (syllabic priming; see Table 1), $F_1(1, 27) = 42.85$, $p < .001$, $\eta^2 = .61$, and $F_2(1, 57) = 52.79$, $p < .001$, $\eta^2 = .48$. In addition, word targets preceded by a phonological-syllable prime were named 10 ms faster than word targets preceded by a single-phoneme prime, $F_1(1, 27) = 10.08$, $p < .005$, $\eta^2 = .27$, and $F_2(1, 57) = 7.76$, $p < .05$, $\eta^2 = .12$. Finally, unlike in Experiment 1 (lexical decision), we found a 17-ms advantage for word targets preceded by a single-phoneme prime relative to word targets preceded by an unrelated prime (phoneme priming), $F_1(1, 27) = 33.72$, $p < .001$, $\eta^2 = .56$, and $F_2(1, 57) = 14.15$, $p < .005$, $\eta^2 = .20$.

Second-Syllable Targets

None of the planned comparisons involving second-syllable targets approached significance (all Fs < 1).

Combined Analysis of Lexical Decision and Naming

To examine whether syllable and phoneme priming were different in the two tasks, we performed a combined analysis of the RT data from Experiments 1 and 2 with task (lexical decision vs. naming) as a between-participants factor. The Priming Condition × Task × Type of Target interaction was significant, $F_1(2, 108) = 3.16, p < .05, \eta^2 = .06$. Overall, for the two tasks combined, syllable priming occurred for first-syllable targets, $F_1(1, 54) = 10.61, p < .01, \eta^2 = .16$, but not for second-syllable targets, $F_1(1, 54) < 1, \eta^2 = .002$. Phoneme priming was present for first-syllable targets only in the naming task, $F_1(1, 27) = 33.72, p < .001, \eta^2 = .56$, but not in the lexical decision task, $F_1(1, 27) < 1$.

GENERAL DISCUSSION

The main findings of the present experiments can be summarized as follows: (a) Phonological priming was obtained in lexical decision and naming tasks with only partial phonological overlap and minimal orthographic overlap between primes and targets; (b) priming effects were obtained for the first—but not the second—syllable in both tasks, which suggests that phonological processing for polysyllabic words is sequential; and (c) there was a priming effect for the initial phonological syllable relative to the initial phoneme (orthographic control) and an unrelated syllable in the lexical decision and the naming tasks, whereas the initial-phoneme priming effect was present only in the naming task.

The observed phonological priming is consistent with proposals that reading involves an early (and possibly mandatory) activation of phonology (e.g., Ferrand & Grainger, 1993; Frost, 1998; Lukatela, Eaton, Lee, Carello, & Turvey, 2002; Lukatela, Frost, & Turvey, 1998; Lukatela & Turvey, 1994; Pollatsek, Lesch, Morris, & Rayner, 1992; Van Orden, 1987; Van Orden, Johnston, & Hale, 1988). It is important to emphasize that, unlike most previous experiments—in which the phonological overlap between primes and targets was typically 100%—the present experiments used primes and targets with minimal overlap, in terms of both graphemes and phonemes. This clearly suggests that phonology plays a key role in reading polysyllabic words.

Furthermore, phonological priming occurred for the first, but not the second, syllable. The presence of faster responses to *fomie-FAUCON* than to *fémie-FAUCON* (but not faster responses to *retôt-GATEAU* than to *retin-GATEAU*) clearly suggests that the first phonological syllable plays a major role in the recognition of visually presented bisyllabic words. This advantage for initial syllables is particularly clear in the lexical decision experiment, as the overlap of a single phoneme, in contrast to overlap of the first syllable, produced only a nonsignificant 1-ms priming effect. Because the syllables were composed of only two phonemes, it is unlikely that the syllable priming effect is a simple summation of priming effects operating at the level of individual phonemes. These results extend some recent results from studies of masked priming in Spanish in which only the initial syllable was manipulated (e.g., Álvarez, Carreiras, & Perea, 2004; Carreiras & Perea, 2002). The results of these studies showed that target words were recognized more rapidly when preceded by primes with which they shared their first syllable (e.g., prime *ju-nas* paired with target *JU-NIO*) than when preceded by primes with which they shared the same number of initial letters but not the first syllable (e.g., prime *jun-tu* paired with target *JU-NIO*). The differential roles of first and second syllables can be accounted for in two ways. One possibility is that words are processed sequentially from left to right (see Coltheart et al., 2001; Taft, 1979, 1991; Taft & Forster, 1976). The second possibility is that initial syllables are given greater weight than subsequent syllables within an activation-based framework.

The present experiments also replicated the masked onset-priming effect in the naming task (see Kinoshita, 2003). This effect refers to the finding that naming responses are faster when a target is preceded by a prime that shares just the initial phoneme with the target (e.g., *save-SINK*), as compared with a control prime that shares no letters with the target (e.g., *farm-SINK*). As in prior research (Forster & Davis, 1991; Grainger & Ferrand, 1996), the present experiments showed no sign of an effect of initial-phoneme overlap in lexical decision. As argued by Grainger and Ferrand (1996), this task difference likely reflects the articulatory output required in naming, which would be sensitive to activation of the initial phoneme. Note that overlap of the first syllable was associated with priming both in lexical decision and in naming, and this advantage was robust relative to initial-phoneme priming in both tasks. Thus, the present results further demonstrate that the type of phonological code generated during visual word recognition is not identical to the one generated for articulatory output, providing evidence against the specific implementation of sublexical phonology in the model of Coltheart et al. (2001). However, the results are consistent with a sequential computation of phonology from orthography as proposed by Coltheart and his colleagues. Taken together, the present findings are consistent with proposals that assume that input phonology is an important step in visual word recognition, and that input phonology may be organized syllabically (Ferrand, Segui, & Grainger, 1996).

In sum, the present findings provide new constraints for the development of computational models of visual word recognition. These models need to account for sequential phonological priming effects that arise extremely rapidly during visual word recognition, and that are present whether or not an articulatory output is required. Given independent evidence for the role of syllables in visual word recognition, one possibility is that phonological syllables are computed serially from a printed word and constrain the process of matching the orthographic input with a semantic interpretation. This possibility and alternative solutions need to be implemented in future models of single-word reading that dare to go beyond the monosyllable.

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