Research Report

Differential Processing of Consonants and Vowels in Lexical Access Through Reading

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ABSTRACT—*Do consonants and vowels have the same importance during reading? Recently, it has been proposed that consonants play a more important role than vowels for language acquisition and adult speech processing. This proposal has started receiving developmental support from studies showing that infants are better at processing specific consonantal than vocalic information while learning new words. This proposal also received support from adult speech processing. In our study, we directly investigated the relative contributions of consonants and vowels to lexical access while reading by using a visual masked-priming lexical decision task. Test items were presented following four different primes: identity (e.g., for the word* joli, joli*), unrelated (*vabu*), consonant-related (*jalu*), and vowel-related (*vobi*). Priming was found for the identity and consonant-related conditions, but not for the vowel-related condition. These results establish the privileged role of consonants during lexical access while reading.*

The present study explores whether consonants and vowels are processed in the same way during the reading of words. Interestingly, although some alphabetical systems, such as those for Arabic and Hebrew, do not traditionally include vowels, almost no model of reading predicts differences between the processing of consonants and vowels. However, such an asymmetry is further suggested by a recent proposal that, across languages, consonants and vowels play different roles in language processing throughout the lifespan (Nespor, Peña, & Mehler, 2003). Consonants would be more important for lexical processing, whereas vowels would be more important for prosodic, syntactic, and rule-based processing. Recently, a heated debate has emerged about whether this proposed universal consonant-vowel asymmetry is a property of the linguistic system or the product of more general acquisition mechanisms that are sensitive to the informational content of the input (Bonatti, Peña, Nespor, & Mehler, 2007; Keidel, Jenison, Kluender, & Seidenberg, 2007). Although this debate might seem intractable, one way to support a linguistic-based interpretation is to provide evidence that this asymmetry does not depend on specific experimental conditions and specific input structure, but rather can be found across tasks, languages, ages, and modalities. Here, we review converging experimental data establishing the broad scope of this asymmetry, starting with developmental data.

Several studies found that French 16- and 20-month-old infants can learn in a single trial two new pseudowords if they differ by one consonant (*/pize/ - /tize/*, a one-feature contrast) but not if they differ by one vowel (even if several phonological features are changed, such as */pize/ - /paze/*; Havy & Nazzi, 2008; Nazzi, 2005; Nazzi & New, 2007). It is important to note that this asymmetry cannot be accounted for solely by positional effects, as 20-month-old infants can also take into account consonantal contrasts in syllable coda positions (*/pid/ - /pit/*, Nazzi & Bertoncini, in press). Evidence of a consonantal advantage was also found in 30-month-old infants in both French and English (Nazzi, Floccia, Moquet, & Butler, in press).

Consonant-vowel asymmetries were also found in “artificial language” learning experiments with adults. French and Italian adults were found to be able to track transitional probabilities at the lexical level in a context of fixed consonants and variable vowels, but not the other way around (Bonatti, Peña, Nespor, & Mehler, 2005; Toro, Bonatti, Nespor, & Mehler, 2008). However, when the task was to detect structural regularities in the stream, thus to learn a rule, adults relied more on vowels (Toro et al., 2008).

Asymmetries also emerged in lexical processing tasks in which adults were presented with pseudowords and asked to

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change a phoneme of each pseudoword in order to transform it into a word (Cutler, Sebastian-Galles, Soler-Vilageliu, & van Ooijen, 2000; Sharp, Scott, Cutler, & Wise, 2005; van Ooijen, 1996). All pseudowords (*kebra*) could be modified by changing either a consonant (to *zebra*) or a vowel (to *cobra*). English-, Dutch-, and Spanish-speaking adults all changed a vowel into another vowel more often and more rapidly than a consonant into another consonant. This finding of a similar consonant advantage in three languages that have very different consonant-vowel ratios suggests that consonant-vowel asymmetries may not crucially depend on the statistical structure of the linguistic input.

Overall, the finding of a consonantal advantage at the lexical level across languages, tasks, and ages supports the proposal by Nespor et al. (2003) that it might be a general property of the linguistic system. The present study addresses some of the questions left open by the earlier adult studies. First, the tasks previously used with adults were very indirect measures of lexical access, and therefore call for more direct measures: We used a lexical decision task with masked priming. Second, in these tasks, position (consonant-initial words were usually used) and number of consonants and vowels in the words were not fully counterbalanced, which might have contributed to the observed asymmetry: We used words with equal numbers of alternating consonants and vowels, half of the words starting with a vowel. Third, all previous studies explored the oral modality: we investigated whether there is a similar asymmetry in reading. This shift to reading was made to evaluate whether the consonantal bias at the lexical level, as a general property of the language system, extends beyond the speech modality.

At present, little is known about the relative contribution of consonants and vowels in reading. This issue was investigated in the context of the two-cycles model (Berent & Perfetti, 1995), which postulates that in languages such as English, because of more transparent grapheme-phoneme correspondences for consonants than vowels, consonants are rapidly and automatically processed in an initial cycle, whereas vowels are processed in a slower and more controlled manner in a second cycle. Accordingly, a processing speed asymmetry was found for English (Lee, Rayner, & Pollatsek, 2001; but see Perry & Ziegler, 2002, for more critical data), but not for languages such as Italian or French in which grapheme-phoneme correspondences are more equally transparent for consonants and vowels (Colombo, 2000; Colombo, Zorzi, Cubelli, & Brivio, 2003; Ferrand, 2004).

In the present study, a lexical decision task with masked priming was used to test the more general claim that consonants are more important than vowels for lexical access in all languages (rather than the more specific processing speed asymmetry of the two-cycles model). A recent study using this kind of task, designed at evaluating the effects of nonadjacent letter transposition on lexical recognition, found priming differences for the transposition of consonants and vowels (Perea & Lupker, 2004). A priming effect was observed when the primes were made by transposing two consonants of the target (*caniso-CASINO*), but not when two vowels were transposed (*anamil-ANIMAL*). At first sight, these results seem to suggest that consonants are less important than vowels at the lexical level, as priming is found when the consonantal structure of the target is not respected. However, these results might be explained by the fact that primes and targets were related by a rule (transposition of letter order), so that the task might tap into mechanisms of rule processing that rely more on vocalic processing (cf. Toro et al., 2008) rather than mechanisms of pure lexical access. Differential effects of consonantal and vocalic information on lexical access should thus be reevaluated without using letter transposition.

In the present study, we test lexical access more directly by presenting adult speakers of French (a language that has a balanced number of consonants and vowels at the phonological level) with primes that are related to the targets according to the presence or not of shared information in the same location. Targets such as *DIVA* or *OPUS* were preceded by four different kinds of primes: identity-related (*diva*, *opus*), consonant-related (preserved consonantal information: *duvo*, *apis*), vowel-related (preserved vocalic information: *rifa*, *onub*), or unrelated (*rufo*, *anib*) primes. Based on Nespor et al. (2003), we predicted more priming from consonant- than vowel-related primes.

METHOD

Participants

Forty-eight students from the Université Paris Descartes took part in the experiment. They were all native French speakers and had normal or corrected-to-normal vision, and no reported language deficit.

Stimuli and Design

The targets were 64 French words, 16 with each of the following orthographic and phonological structures as defined by the order of consonants (Cs) and vowels (Vs): CVCV, VCVC, CVCVCV, and VCVCVC. Consonant-initial (M = 7.22; SD = 13.27) and vowel-initial (M = 6.81; SD = 11.25) targets had similar frequencies, $t(62) = 0.13$. Primes had the same orthographic and phonological structure as the targets. The four types of prime were identity-related (*diva-DIVA*), consonant-related (*duvo-DIVA*), vowel-related (*rifa-DIVA*), and unrelated (*rufo-DIVA*).

Eighty distractors (16 four-letter words, 48 five-letter words, 16 six-letter words) of varied orthographic and phonological structure were also presented. Finally, 144 pseudowords were constructed that respected French phonotactic rules and had the same proportion of various orthographic and phonological structures as the words (targets and distractors). One out of four distractors or pseudowords was preceded by an identity prime, whereas three out of four were preceded by unrelated or partially related primes.

Four experimental lists were constructed in which prime-target pairs were rotated according to a Latin-square design, so that a given target was primed by one type of prime in each list, and by all different types of prime across the four lists. Each participant was presented with only one list.

Procedure

Participants were tested individually in a quiet room. They were asked to indicate as quickly and accurately as possible whether the presented letter string appearing on the computer screen formed an existing French word or not. They did so by pressing "q" or "l" on the keyboard. Each trial began with the presentation of the mask ("######") for 500 ms. It was followed by the prime, presented in lowercase letters for 50 ms, and then by the target, presented in uppercase letters (with accents on vowels when appropriate); the target remained visible until the participant responded (with a maximum presentation of 3 s). Between trials, there was a 1,300-ms interval during which a black screen was shown. The order of presentation of the stimuli was randomized for each participant and presented with the E-Prime 1.1 software (Psychology Software Tools). The test items were preceded by 20 practice trials. The participants could take a short break after each block of 96 trials. The experiment lasted approximately 20 min.

RESULTS

Because there were no effects on response accuracy, only reaction time (RT) analyses for correct responses are reported. All RTs faster than 300 ms or slower than 1,400 ms were identified as outliers and removed (0.45% of the RTs). Moreover, for each subject, RTs of more than 2.5 *SD* around the mean were discarded (2.68% of the RTs). Two target words were removed from the analyses because they had more than 33% of errors (*ATONAL* and *AVILIR*). For mean lexical RTs and error rates, see Table 1.

Analyses of variance showed a significant main effect of prime type, $F_1(3, 47) = 13.58, p < .001$; $F_2(3, 60) = 10.84, p < .001$, and no effect of target type (consonant-initial vs. vowel-initial), $F_1(1, 47) = 1.01$; $F_2(1, 60) = 0.3$. The interaction between prime type and target type approached but failed to reach significance, $F_1(3, 47) = 2.4, p = .08$; $F_2(3, 60) = 2.22, p = .09$. Thus, the consonant-initial and vowel-initial conditions were merged. Planned comparisons showed that targets preceded by consonant-related primes were processed faster than targets preceded by either unrelated (18-ms difference), $t_1(47) = -2.32$, $p < .05$; $t_2(61) = -3.11, p < .01$, or vowel-related primes (20-ms difference), $t_1(47) = -3.01, p < .01$; $t_2(61) = -2.08, p < .05$. There was no difference between the vowel-related and unrelated conditions, $t_1(47) = 0.22$, n.s.; $t_2(61) = 0.07$, n.s.

To rule out alternative interpretations of the observed consonant-vowel asymmetry, we conducted control analyses to evaluate the potential impact of various linguistic factors on adults' performance in the present study. The first factor was the number of phonological features (the binary parameters, such as voiced/voiceless, used to define all phonemes and distinguish between them) shared between the targets and the primes. Controlling for the possible involvement of this factor is important given evidence of its role in silent reading (Lukatela, Eatin, Lee, & Turvey, 2001) and differences in the phonological feature distance between the targets and the vowel- versus consonant-related primes (8.3 vs. 5.3, respectively), $t(61) = -8.43, p < .001$, due to the fact that the consonantal space is defined using more phonological features than the vocalic space (eight vs. four features; Dell, 1985). Second, we evaluated the possible impact of letter frequency effects (calculated using the book corpus of Lexique 3; New, Pallier, Ferrand, & Matos, 2001; New, Pallier, Brysbaert, & Ferrand, 2004), and more precisely the possible effect of mean shared-letter (between a prime and its target) frequency, which was significantly higher for the vowel-related primes (246,341) than for the consonant-related primes (184,134), $t(61) = -4.33, p < .001$. Third, we used Lexique 3 to calculate the similarity of the primes to other French words because increased similarity might facilitate priming. These analyses revealed differences between the consonant- versus vowel-related primes for bigram counts (5,070 vs. 6,038), $t(61) = 1.64, p = .05$) and bigram frequencies (21,196 vs. 24,334), $t(61) = 1.38, p = .09$, although not for number of neighbors (1.74 vs. 1.72), $t(61) = 0.03, p = .49$, and neighbor frequencies (20.2 vs. 24.8), $t(61) = -0.08, p = .53$). Then, the potential role of these factors in determining the consonant-vowel asymmetry was evaluated by correlating these variables with the amount of vowel-related priming ($RT_{unrelated} - RT_{vowel\text{-}related}$), consonant-related priming ($RT_{unrelated} - RT_{consonant\text{-}related}$) and relative consonant-vowel priming ($RT_{consonant\text{-}related} - RT_{vowel\text{-}related}$). As can be seen from Table 2, none of these correlations was sig-

TABLE 1

Mean Lexical-Decision Reaction Times (RTs; in Milliseconds) and Percentage of Errors for Consonant-Initial and Vowel-Initial Words

	Type of target					
	Consonant-initial structure		Vowel-initial structure		All targets	
Priming condition	RT	Percentage of error	RT	Percentage of error	RT	Percentage of error
Identity (e.g., *diva-DIVA*)	592	8.3	615	13.3	603	10.8
Consonant-related (e.g., *duvo-DIVA*)	627	9.9	635	15.0	631	12.4
Vowel-related (e.g., *rifa-DIVA*)	658	13.5	643	17.5	651	15.5
Unrelated (e.g., *rufo-DIVA*)	648	9.6	650	14.7	649	12.1

TABLE 2
Correlation Between Priming and Independent Variables

Variable	Vowel-related priming	Consonant-related priming	Relative consonant-vowel priming
Number of phonological features	$\rho = -.09$, $t(60) = -0.74$	$\rho = .06$, $t(60) = 0.48$	$\rho = .13$, $t(60) = 1.07$
Letter frequency (log)	$\rho = .07$, $t(60) = 0.57$	$\rho = .09$, $t(60) = 0.67$	$\rho = -.02$, $t(60) = -0.21$
Neighbor frequency (log)	$\rho = -.08$, $t(60) = -0.66$	$\rho = -.10$, $t(60) = -0.80$	$\rho = .03$, $t(60) = -0.21$
Neighbor count	$\rho = -.13$, $t(60) = -0.98$	$\rho = -.21$, $t(60) = -1.66$	$\rho = .03$, $t(60) = 0.28$
Bigram frequency (log)	$\rho = -.10$, $t(60) = -0.82$	$\rho = -.12$, $t(60) = 0.93$	$\rho = -.04$, $t(60) = -0.29$
Bigram count	$\rho = -.10$, $t(60) = -0.78$	$\rho = .12$, $t(60) = 0.97$	$\rho = .01$, $t(60) = 0.09$

Note. Priming was calculated as the difference between reaction times (RTs) as follows: vowel-related priming = $RT_{unrelated} - RT_{vowel\text{-}related}$; consonant-related priming = $RT_{unrelated} - RT_{consonant\text{-}related}$; relative consonant-vowel priming = $RT_{consonant\text{-}related} - RT_{vowel\text{-}related}$.

nificant, implying that all these differences between the two types of primes cannot explain the consonant-vowel bias found in the present study.

DISCUSSION

The present results show different priming effects on lexical decision depending on whether the primes and targets share consonants or vowels. Not only do consonant-related primes prime the targets more than do vowel-related primes, but we did not observe any significant priming for vowel-related primes. It looks like consonantal information is enough to prime the target, whereas this is not the case for vocalic information. Given the lack of a speed difference in consonant-vowel processing in French (Ferrand, 2004), the present asymmetry indicates that lexical representations are accessed more reliably through consonantal than vocalic information. The control analyses that we conducted rule out alternative interpretations in terms of differences between the consonant- and vowel-related primes in phonological feature distance, letter frequency, neighborhood density, and bigram characteristics. Most importantly, although the consonant advantage in previous studies on this issue might have (at least in part) resulted from having used mostly consonant-initial words that contained more consonants than vowels (Bonatti et al., 2005; Cutler et al., 2000; van Ooijen, 1996), the present asymmetry cannot be explained by the number or position of the letters and phonemes, because the effects were present in both the consonant- and vowel-initial targets.

Our finding of a consonantal bias in French is important given that French is a language in which vowels are almost as numerous as consonants, and therefore a language in which the consonant-vowel asymmetry might have been less marked. Our results show that this bias has a broad scope, as it has been found in different lexical-related tasks and age groups in all languages tested thus far: French (Bonatti et al., 2005; Havy & Nazzi, 2008; Nazzi, 2005; Nazzi et al., in press), English (Cutler et al., 2000; Nazzi et al., in press), Dutch (van Ooijen, 1996), and Spanish (Cutler et al., 2000). Taken together, it appears that the consonantal lexical processing bias is more likely to be due to general properties of the linguistic system (Bonatti et al., 2005, 2007) than to be the product of consonant-vowel differences in information content (Keidel et al., 2007).

Third, our results establish that the scope of the consonantal bias at the lexical level is not even limited to the speech modality. It actually extends to lexical access through reading. This finding challenges all current models of word reading (e.g., SOLAR: Davis, 1999; SERIOL: Whitney, 2001; LCD: Dehaene, Cohen, Sigman, & Vinckier, 2005; overlap open-bigram model: Grainger, Granier, Farioli, Van Assche, & van Heuven, 2006) because none of them (except for the two-cycle model in Berent & Perfetti, 1995) considers consonants and vowels differently. It will be interesting to see how these models could be modified in order to take such differences into account. Finally, the present results could have important consequences for methods of reading acquisition and for our understanding of how phonological and orthographic codes are activated during reading.

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