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Behavioral and Electrophysiological Study of Phonological Priming between Bisyllabic Spoken Words

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Abstract

■ Phonological priming between bisyllabic (CV.CVC) spoken items was examined using both behavioral (reaction times, RTs) and electrophysiological (event-related potentials, ERPs) measures. Word and pseudoword targets were preceded by pseudoword primes. Different types of final phonological overlap between prime and target were compared. Critical pairs shared the last syllable, the rime or the coda, while unrelated pairs were used as controls. Participants performed a target shadowing task in Experiment 1 and a delayed lexical decision task in Experiment 2. RTs were measured in the first experiment and ERPs were recorded in the second experiment. The RT experiment was carried out under two presentation conditions. In Condition 1 both primes and targets were presented auditorily, while in Condition 2 the primes were presented visually and the targets auditorily. Priming effects were found in the unimodal condition only. RTs were fastest for syllable overlap, intermediate for rime overlap, and slowest for coda overlap and controls that did not differ from one another. ERPs were recorded under unimodal auditory presentation. ERP results showed that the amplitude of the auditory N400 component was smallest for syllable overlap, intermediate for rime overlap, and largest for coda overlap and controls that did not differ from one another. In both experiments, the priming effects were larger for word than for pseudoword targets. These results are best explained by the combined influences of nonlexical and lexical processes, and a comparison of the reported effects with those found in monosyllables suggests the involvement of rime and syllable representations. ■

INTRODUCTION

The assignment of a meaningful interpretation to a stretch of speech requires the mapping between the incoming signal and stored word forms. This mapping process, which leads to spoken word recognition, depends upon the structural properties of word representations, the organization of the mental lexicon, and the prelexical input representations used in lexical access (see Frauenfelder & Floccia, 1999 for an introduction). One tool psycholinguists have developed to study spoken word recognition is phonological priming (for an overview: Zwitserlood, 1996). The logic of this paradigm is that processing a stimulus—the prime—should affect the processing of a subsequent stimulus—the target—when prime and target share some formal information that matches a representation involved in lexical access. The priming situation is rather far from naturalistic conditions of speech processing. However, as priming enables to bias the state of the lexical processing system prior to a critical stimulation, it appears an attractive indirect way to approach analytically how words are recognized in a situation of real communication.

The large phonological priming literature shows a remarkable dissociation depending on overlap location. Studies that focused on the effect of initial overlap between two successively presented items (e.g., sad–sack) have obtained rather messy results. In tasks as lexical decision and identification in noise, both facilitation and inhibition, or more often no effect at all, have been reported (see the review by Radeau, Morais, & Seguí, 1995, Appendix A; and additional results by Cutler and Chen, 1995; Goldinger, 1998; Praamstra, Meyer, & Levelt, 1994; Praamstra & Stegeman, 1993). And, in the target shadowing task (Radeau, Morais, & Dewier, 1989), what underlies the often reported inhibitory effect between monosyllabic words (Brown, 1990; Radeau, 1995; Radeau et al., 1995; Slowiaczek & Hamburger, 1992) is a matter of controversy (see Goldinger, 1999; Hamburger & Slowiaczek, 1996, 1999; Radeau & Colin, 1996).

In contrast to initial overlap, final overlap has systematically produced facilitatory effects, independently of the task performed: identification in noise (Slowiaczek, Nusbaum, & Pisoni, 1987), lexical decision (Slowiaczek, McQueen, Soltano, & Lynch, 2000; Radeau, Seguí, & Morais,1994, 1995; Praamstra et al., 1994; Praamstra & Stegeman, 1993; Corina, 1992) and shadowing (Slowiac-

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zek et al., 2000; Radeau, 1995; Radeau et al., 1995). The final overlap facilitation is transient: the effect was shown to decrease when the interstimulus interval (ISI) was lengthened (Radeau et al., 1995). Studies using monosyllabic words have clearly shown that final overlap facilitation resulted from the two items sharing at least the phonological rime[1](e.g., back–lack): that is, the vowel and the following optional consonants in a syllable (e.g., e in be; ack in lack). In fact, using items with a CCVC consonant–vowel phonological structure that shared one, two, or three phonemes from the end, Radeau (1995) observed facilitation of rime overlap [VC] (flamme–tram) but no increase in this effect when the overlap included a consonant of the onset[2] in addition to the rime [CVC] (gramme–tram). When the two items shared only the last consonant—the coda—(flemme–tram), no effect was found. Further evidence that rime overlap is required to obtain final facilitation has recently been provided by Slowiaczek et al. (2000). These authors showed that facilitation was no longer observed when prime and target shared the vowel but none of the following consonants (e.g., shade–bake) so that rime overlap was not fulfilled.

The rime effect seems to occur rather early in the course of target processing. Indeed, it has been shown to be modality-dependent: the effect requires that prime and target be presented auditorily, and dissipates under crossmodal presentation (Radeau et al., 1994; Radeau, 1995). Furthermore, the failure to obtain any modulation of the effect by prime-target relative frequency (Radeau et al., 1995) or prime lexicality (words vs. pseudowords; Slowiaczek et al., 2000; Radeau et al., 1994; Burton, 1992) is also consistent with such a prelexical view.

Bisyllabic items have only been used in studies that have primarily focused on the effect of final syllable overlap (Titone & Connine, 1997; Cutler & Chen, 1995; Cutler, van Ooijen, & Norris, 1999; Burton, 1992; Corina, 1992; Emmorey, 1989). In these experiments, facilitation was found using both lexical decision and shadowing, and for both word and pseudoword primes. One exception is a study by Emmorey (1989, Exp. 1) using words with a weak–STRONG syllabic stress pattern that is uncommon in English (strong syllables are reported in uppercase letters). Final syllable overlap gave rise to facilitation when the strong syllable corresponded to the morphemic root (subMIT–perMIT), but produced no effect when it had no morphological status (duRESS–caRESS).

As regards the level of representation that gives rise to final overlap facilitation between bisyllabic items, the data from overlap length manipulations are inconsistent. Using words with the STRONG–weak common stress pattern in English, Emmorey (1989, Exps. 2 and 3) found a large facilitatory effect of syllable overlap (TANgo–CARgo), which was independent of the morphological status of the syllable, but no effect of a rime overlap, which in this case always corresponded to an inflectional suffix (DANcing–GRAzing). By contrast, Burton (1992, Exp. 2) obtained facilitatory effects of similar magnitude for syllable overlap (FOrage–COUrage) and rime overlap (BONdage–COUrage), where in this case the rime unit was part of the root, or a derivation, rather than an inflection.

The results of a study by Titone and Connine (1997) shed further light on the representations involved. These authors used phonological priming to examine whether any syllabification principle is applied during on-line spoken word recognition, and if so, what principle is used. Pairs of CVCCVC items were presented in which a word or pseudoword target (e.g., MARKet or TARKet, respectively) was primed by a pseudoword sharing all but the first phoneme with the target, in one of three conditions. In two conditions, primes had been artificially syllabified by the insertion of silence in accordance either with the Maximal Onset Principle (e.g., Pulgram, 1970) or with the Stress Principle (Bailey, 1978). The Maximal Onset Principle states that the maximum number of consonants attach to a syllable onset provided this sequence exists at the beginning of a word (LAR.ket; the "." indicates a syllable boundary). The Stress Principle (Bailey, 1978) states that consonants preferentially attach to stressed syllables[3] regardless of phonotactics (LARK.et). The third condition, in which primes had not been artificially syllabified, served as control (FARKet). The largest facilitation was found in the control condition that used natural items. In the artificial conditions, primes syllabified in agreement with the Maximal Onset Principle produced a far greater facilitation than those syllabified according to the Stress Principle. In the case of word targets, primes segmented according to the Maximal Onset Principle were equivalent to the unmanipulated controls. These results suggest both that phonological priming is sensitive to some syllabification cues, and that the Maximal Onset Principle of syllabification has a perceptual reality in spoken word recognition, at least for English.

Leading psycholinguistic models of spoken word recognition fail to provide an account completely satisfactory of (1) the phonological facilitation that (2) is restricted to final overlap. The Cohort model predicts priming effects indeed, but only for initial overlap. Whereas the original version predicted facilitatory effects (Marslen-Wilson & Welsh, 1978), the current version that incorporates transient bottom-up active inhibition predicts inhibitory effects of initial overlap (Gaskell & Marslen-Wilson, 1996, 1998; Marslen-Wilson, 1993). The bottom-up inhibition mechanism reduces the activation level of prime competitors that no longer match the speech input, including the target. In NAM, the Neighborhood Activation Model (Luce, 1986; see also Luce, Pisoni, & Goldinger, 1990; Luce & Pisoni, 1998) as in PARSYN (Luce, Goldinger, Auer, & Vitevitch, 2000), a connectionist instantiation of NAM able to deal with priming, target identification is negatively affected by the density and the frequency of the target neighbors. Presentation of a phonologically related prime should thus have two opposite effects. On the one hand, at the word-level, as a target neighbor of which the frequency is enhanced, the phonologically related prime should slow down target identification. But on the other hand, at the sublexical levels, the residual activation left by prior presentation of shared segments should speed up target sublexical processing. How these effects combine still needs to be addressed by simulations. Moreover, as NAM was conceived for the processing of short words, and therefore does not take overlap location into account when computing the neighborhood, no difference due to overlap location should be observed in the priming effects. In contrast to PARSYN (see above), the connectionist models TRACE (McClelland & Elman, 1986; see also Frauenfelder & Peeters, 1990, 1998) and Shortlist (Norris, 1994; Norris, McQueen, Cutler, & Butterfield, 1997) are technically (although not theoretically) unable to deal with priming effects. The major limitation of these models is that their current architectures offer no connection between lexical nodes that do not overlap in time. Primes and targets presented consecutively will therefore be processed completely independently.

The first aim of the present study was to specify the representations involved in the facilitatory effect of final overlap between bisyllabic items, using both behavioral and electrophysiological measures. The experiments were conducted in French. In this language, the specific role of the syllable in speech processing has been widely documented using different paradigms including sequence detection[4] (Mehler, Dommergues, Frauenfelder, & Seguí, 1981), phoneme monitoring[5] (Seguí, Dupoux, & Mehler, 1990), attentional allocation[6] (Pallier, Sebastián-Gallés, Felguera, Christophe, & Mehler, 1993), phonological migrations[7] (Kolinsky, Morais, & Cluytens, 1995), and word-spotting[8] (Dumay, Banel, Frauenfelder, & Content, 1998; see also Dumay, Content, & Frauenfelder, 1999). Three types of overlap were compared in the present study. Primes and targets with CV.CVC phonological structure shared either the last phoneme (the coda), the last two phonemes (the rime), or the last three phonemes (the syllable). The predicted pattern of results depends on what form of representation underlies final priming between bisyllabic items. If the final overlap effect depends upon the amount of shared acoustic–phonetic information, the effect should increase linearly with the number of shared phonemes. By contrast, different patterns of results would be expected if priming relies upon specific linguistic units like the rime and/or the syllable. Exclusive reliance on rime units should lead to effects of similar magnitude for rime and syllable overlap, but to no effect of coda overlap. Likewise, exclusive reliance on syllabic units should lead to facilitation from syllable overlap only. If both units are involved, the syllabic effect should be larger than the rime effect and there should be no effect of coda overlap.

The amount of priming due to target recognition was assessed using both words and pseudowords as targets—as words only are stored, only words can be recognized. One possible interpretation of final phonological priming, which is compatible with the general framework of a cohort-like model of word recognition, is that the effect occurs during the lexical selection phase (Radeau et al., 1995). The main idea is that the functional role of the representations activated by the final information in the prime is to speed up lexical selection of the target once the target cohort is activated. According to this view, final overlap priming should be restricted to word targets; no effect should be observed for pseudowords because these are not stored in the lexicon.

Experiment 1 used behavioral measures (reaction times [RTs] and error rates) to assess final phonological priming, while participants performed target shadowing. An additional aim of this experiment was to determine whether the effect was modality-specific. To this end, two conditions of presentation were compared. In one condition both primes and targets were presented auditorily, while the other condition used a crossmodal procedure, in which primes were presented visually and targets auditorily.

The rationale underlying the unimodal versus crossmodal comparison is based on neuropsychological evidence suggesting that written and spoken words are processed by separate and modality-specific input lexicons (cf. Seron & Jeannerod, 1994 for a review). These lexicons receive inputs from the auditory and the visual analysis systems, and are assumed to contain only phonological and orthographical representations, respectively. The word meanings are stored in a common higher-level supramodal system. Studies using positron emission tomography (PET) have shown that the visual analysis takes place in the extrastriate cortex (Petersen, Fox, Posner, Mintum, & Raichle, 1988; Petersen, Fox, Snyder, & Raichle, 1990), while the acoustic analysis involves the superior temporal gyrus, which includes the primary and secondary auditory cortex (Mazoyer et al., 1993; Zatorre, Evans, Meyer, & Gjedde, 1992). The visual and auditory word form lexicons are assumed to be located in different areas, but their precise location remains a focus of controversy (Howard et al., 1992; Frith, Friston, Liddle, & Frackowiak, 1991; Petersen et al., 1988, 1990). While an effect arising at, or after, the level of the supramodal semantic system is expected to be of comparable size under unimodal and crossmodal presentations, an effect arising at an earlier stage should be modality-specific.

Experiment 2 assessed final phonological priming using Event-Related Brain Potentials (ERPs; see Rugg & Coles, 1995 for an introduction) recorded while participants performed a delayed go/no-go nonword decision. ERPs allow the tracking of the time-course of psycholinguistic events (Kutas & Van Petten, 1994 for a review) and may therefore provide a more sensitive measure of phonological priming than behavioral measures alone.

The ERP components associated with semantic priming have been extensively documented. A negative component peaking at 400 msec (N400) after target onset has been shown to reflect semantic processing. The reduction in the amplitude of the N400 correlated with semantic priming, first described for printed words in sentential and single word contexts (Nobre & McCarthy, 1994; Besson, Kutas, & Van Petten, 1992; Bentin, McCarthy, & Wood, 1985; Rugg, 1985; Kutas & Hillyard, 1980), was later replicated for spoken words, where it was found to begin earlier and to be of longer duration (Besson, Faita, Czternasty, & Kutas, 1997; Ford et al., 1996; Bentin, Kutas, & Hillyard, 1993; Holcomb & Neville, 1990; McCallum, Farmer, & Pocock, 1984). The sensitivity of the N400 rapidly turned out to be not restricted to semantic congruency. Among other linguistic dimensions, phonological similarity was also shown to elicit N400 modulations. In the domain of rhyming written words, N400 effects were observed, provided that rhyme-judgment was the assigned task (Barrett & Rugg, 1989; Kramer & Donchin, 1987; Rugg, 1984a, 1984b; Rugg & Barrett, 1987; Polish, McCarthy, Wang, & Donchin, 1983; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980). In the auditory domain, these N400 modulations were obtained not only in metaphonological (i.e., rhyme-judgment) but also in nonmetaphonological tasks (i.e., lexical decision; see Praamstra & Stegeman, 1993).

There are indeed several studies of the electrophysiological correlates of phonological priming in the auditory modality, all of which used exclusively monosyllabic items. The results they report are quite clear. Radeau, Besson, Fonteneau, and Castro (1998) and Praamstra and collaborators (Praamstra & Stegeman, 1993; Praamstra et al., 1994) found a reduction in the N400 amplitude for rime overlap prime-target pairs, relative to a control condition with no overlap. The N400 rime effect was obtained whether the lexical decision task used in these studies required an immediate (Radeau et al., 1998; Praamstra & Stegeman, 1993) or a delayed response (Praamstra et al., 1993). Radeau et al. (1998) also compared semantic and rime priming for monosyllabic words and found that the same ERP component, namely the N400, was influenced by both types of priming. The main difference between the effects was that the reduction in the amplitude of the auditory N400 was smaller for rime than for semantic priming. Experiment 2 was designed to gain further evidence regarding the ERP components associated with final phonological priming, using bisyllabic items.

EXPERIMENT 1

The major aim of Experiment 1 was to study final phonological priming between bisyllabic items, using both RTs and error rates as dependent variables. Three types of primes were compared, which shared either the coda, the rime, or the whole final syllable with the targets. All the items had a CV.CVC consonant–vowel phonological structure. As explained in the Introduction, neuropsychological and brain imaging data suggest that word processing is carried out by separate modality-specific systems and separate word form stores before the supramodal semantic level is accessed. In order to assess the locus of the effect, two presentation conditions were compared. Condition 1 used unimodal auditory presentation of primes and targets, while Condition 2 used crossmodal visual–auditory presentation. In both conditions, participants performed a target-shadowing task in which they had to repeat back the spoken targets as quickly and accurately as possible. In Condition 2, catch-trials were inserted in some fillers. In these trials, the prime contained nonalphabetical $ signs to be detected by the participants. Such an additional task, necessary to ensure that the participants processed the visual primes, has been used successfully by Radeau (1995) in a study also using the shadowing task. In this study, the inhibitory effect of initial overlap found in the auditory modality was replicated with the same magnitude, using crossmodal visual–auditory presentation. Clearly, performing this secondary task on the primes does not appear to affect phonological priming effects.

Results

Incorrect responses and RTs longer than 1500 msec or shorter than 300 msec were discarded from the analyses. A vocal response was classified as incorrect when at least one of its phonemes diverged from the expected response, or when there was a hesitation. In the crossmodal condition, all participants succeeded in detecting perfectly the nonalphabetical sign in the catch trials.

Reaction Times Analyses

(A) General analyses. The main results are a strong facilitatory priming effect of syllable overlap (40 msec) and a smaller effect of rime overlap (20 msec) in the unimodal condition, and no overlap effect in the crossmodal condition. In the unimodal condition, both effects tended to be larger for word (51 msec for syllable and 28 msec for rime) than for pseudoword targets (29 msec for syllable and 13 msec for rime). Mean RTs by participants ($F1$) and items ($F2$) were analyzed by general ANOVAs including Prime Modality (auditory vs. visual) as between-subject factor and, Lexicality (word vs. pseudoword) and Overlap (control, coda, rime or syllable) as within-subject factors (see Table 1).

The Modality effect was significant by items only ($F1 < 1$; $F2(1, 158) = 18.38$, $MSE = 11421.2$, $p < .0001$). The mean RTs were 25 msec slower in the unimodal (746 msec) than in the crossmodal condition (721

Table 1. Mean RT (msec) and Error Rate (%) in Each of the Eight Conditions for Both Types of Presentation

		Prime Type				Control vs.		
		Control	*Coda*	*Rime*	*Syllable*	*Coda*	*Rime*	*Syllable*
Unimodal presentation								
Word target	RT	749	744	721	698	5	28*	51**
	ER	0.8	0.7	0.5	0.6	0.1	0.3	0.2
Pseudoword target	RT	778	774	765	749	4	13*	29**
	ER	3.8	3.5	3	3	0.3	0.8	0.8
Crossmodal presentation								
Word target	RT	709	709	699	699	0	10	10
	ER	0.8	1	1.5	1	– 0.2	– 0.6	– 0.2
Pseudoword target	RT	736	736	735	740	0	1	– 4
	ER	4.4	4.4	3.4	3.4	0	0.9	0.9

The difference between each experimental condition and its respective control is indicated in the right part of the table.

*Indicates that it was significant by participants only.

**Indicates that the effect was statistically significant by both participants and items.

msec). The Lexicality effect was highly significant ($F1(1, 94) = 170.58$, $MSE = 1437.5$, $p < .0001$; $F2(1, 158) = 27.94$, $MSE = 15159.7$, $p < .0001$) and did not interact with Modality ($F1 = 1.18$; $F2 < 1$). On the whole, the mean RTs were 36 msec slower for pseudoword (752 msec) than for word targets (716 msec). The effect of Overlap was highly significant too ($F1(3, 282) = 37.54$, $MSE = 514.3$, $p < .0001$; $F2(3, 474) = 5.30$, $MSE = 5976.5$, $p < .01$), and interacted with Modality ($F1(3, 282) = 25.04$, $MSE = 514.3$, $p < .0001$; $F2(3, 474) = 3.19$, $MSE = 5947.5$, $p < .025$). The Overlap × Lexicality interaction was also significant but by participants only ($F1(3, 282) = 7.31$, $MSE = 511.9$, $p < .0001$; $F2 = 1.21$). In the analysis by participants, while significant for both levels of Lexicality, the Overlap effect was larger for word ($F1(3, 282) = 41.99$, $MSE = 476$, $p < .0001$) than for pseudoword targets ($F1(3, 282) = 5.57$, $MSE = 550.1$, $p < .001$). As the Overlap × Modality interaction was highly significant, separate ANOVAs including Overlap and Lexicality as factors were performed for the unimodal and the crossmodal conditions.

(B) Separate analyses. In the unimodal condition, the Overlap effect was highly significant ($F1(3, 141) = 50.83$, $MSE = 617.3$, $p < .0001$; $F2(3, 474) = 7.23$, $MSE = 6775.5$, $p < .0001$). The syllable effect was significant by participants and items: across word and pseudoword targets, RTs were 40 msec faster in the syllable than in the control condition ($F1(1, 47) = 92.96$, $MSE = 820.5$, $p < .0001$; $F2(1, 158) = 20.59$, $MSE = 5733.9$, $p < .0001$). RTs were also 20 msec faster in the rime than in the control condition. This effect was significant by participants, but only marginally by items ($F1(1, 47) = 38.97$, $MSE = 518.7$, $p < .0001$; $F2(1, 158) = 3.23$, $MSE = 9060.2$, $p = .07$). There was no effect of coda overlap (both Fs < 1). Both rime and syllable conditions were faster than the coda condition (Rime: 16 msec; $F1(1, 47) = 20.82$, $MSE = 599.5$, $p < .0001$; $F2(1, 158) = 3.26$, $MSE = 5855.6$, $p = .073$; Syllable: 36 msec; $F1(1, 47) = 88.13$, $MSE = 685.2$, $p < .0001$; $F2(1, 158) = 10.15$, $MSE = 9506.2$, $p < .002$). The 20 msec difference between the rime and the syllable conditions was also significant ($F1(1, 47) = 24.52$, $MSE = 732.6$, $p < .0001$; $F2(1, 158) = 5.74$, $MSE = 5190.6$, $p < .02$).

The Overlap × Lexicality interaction was significant by participants but not by items ($F1(3, 141) = 6.91$, $MSE = 413.6$, $p < .00025$; $F2 < 1$). In the participant analysis, phonological priming was larger for word than for pseudoword targets, but was nevertheless significant for both (Words: $F1(3, 141) = 49.27$, $MSE = 536.8$, $p < .0001$; Pseudowords: $F1(3, 141) = 15.75$, $MSE = 494.1$, $p < .0001$). The effect of syllable overlap was larger for word than for pseudoword targets ($F1(1, 47) = 16.30$, $MSE = 367.9$, $p < .0002$), but was nevertheless significant both for words (51 msec; $F1(1, 47) = 102.79$, $MSE = 608.3$, $p < .0001$) and pseudowords (29 msec; $F1(1, 47) = 34.05$, $MSE = 580.1$, $p < .0001$). The effect of rime overlap was also larger for word than for pseudoword targets ($F1(1, 47) = 5.38$, $MSE = 461$, $p < .025$) but was significant for words (28 msec; $F1(1, 47) = 39.58$, $MSE = 465.5$, $p < .0001$) as well as for pseudowords (13 msec; $F1(1, 47) = 8.30$, $MSE = 514.2$, $p < .001$). In contrast, for both levels of Lexicality, RTs in the coda and in the control conditions were not statistically different (both $F1$ close to 1).

In the crossmodal condition, no phonological priming occurred (see Table 1). Overlap had no effect ($F1(3, 141) = 1.97$, $MSE = 411.2$, $p < .15$; $F2 < 1$) and did not interact with Lexicality ($F1(3, 141) = 1.80$, $MSE = 610.2$, $p < .2$; $F2 < 1$).

Error Analyses

As can be seen in Table 1, the overall error rate was quite low (2.24%) and appeared to be insensitive to phonological overlap. The raw scores of errors by participants ($F1$) and items ($F2$) were analyzed by general ANOVAs using the same factors as in the RT analyses. The effect of Modality was not significant by participants while it was by items ($F1(1, 94) = 1.81$; $F2(1, 158) = 4.27$, $MSE = 1.1$, $p < .05$). The error rate in the unimodal condition (2%) was slightly lower than in the crossmodal condition (2.5%). The effect of Lexicality was highly significant ($F1(1, 94) = 139.30$, $MSE = 60.8$, $p < .0001$; $F2(1, 158) = 10.29$, $MSE = 34.8$, $p < .01$). The error rate was higher for pseudoword (3.6%) than for word targets (0.9%). No other main effect or interaction reached significance in the Error analyses (all Fs less than or close to 1).

Discussion

The present experiment was designed to examine the influence of three types of phonological overlap, using RT and error rate measures. The bisyllabic items had a CV.CVC structure and shared either one phoneme (i.e., the coda), two phonemes (i.e., the rime), or three phonemes (i.e., the syllable) from the end. Target lexicality was manipulated (words vs. pseudowords) while only pseudowords were used as primes. Two priming situations were compared: auditory–auditory versus visual–auditory presentation. The main result of Experiment 1 is that phonological priming was found in the unimodal condition only; no effect occurred with visual–auditory presentation even though the shadowing task performed on the target could have encouraged phonological recoding of the prime and the subsequent use of this information to pronounce the target.

The absence of priming in the crossmodal situation is difficult to explain in terms of a reduction in participants' alertness relative to the unimodal situation. Indeed, contrary to the A–A condition, the V–A one required that the participants kept their eyes open looking at the screen to detect catch trials during prime presentation.

The fact that the final overlap effect vanishes in crossmodal presentation is consistent with the data obtained using the reverse auditory–visual situation by Cutler et al. (1999) and Radeau et al. (1994), who both found no evidence of final overlap facilitation in monosyllabic and bisyllabic items, respectively. These results suggest that the effects obtained under unimodal presentation occur prior to the supramodal semantic level. They are consistent with the view that visual and auditory word processing is carried out by different subsystems.

The present final overlap facilitation was found using a short ISI (20 msec). As strategy-based effects are known to benefit from ISI lengthening (Neely, 1977; Posner & Snyder, 1975), the finding by Radeau et al. (1995) that final overlap facilitation decreased when ISI was lengthened from 20 msec to 500 msec strongly argues against the idea that a final phonological priming effect like the one reported here is purely strategic. Furthermore, the finding of no facilitation with the crossmodal presentation, a situation in which strategies had more time to develop because prime duration was much longer than needed for visual processing also provides arguments in this respect. Nevertheless, debriefing of the participants at the end of the experiment revealed that most of them were aware of the phonological similarity between primes and targets, independently of the presentation condition (for 32 of 48 participants in the unimodal condition and for 34 of 48 participants in the crossmodal condition). Note, however, that since no phonological priming was found in the crossmodal condition, awareness of phonological similarity is unlikely to explain the present results.

In the unimodal condition, the data provide clear evidence that final phonological overlap speeds up target processing. There was a strong facilitatory effect of syllable overlap, a smaller and less reliable effect of rime overlap, and no effect of coda overlap. Rime overlap and syllable overlap thus seem to play a different role in the effect of final phonological similarity. As regards target lexicality, although the priming effects tended to be larger for words than for pseudowords, they were not restricted to words. Because the interaction was not completely reliable (it was statistically significant by participants but not by items), this tendency will be reconsidered in the light of the results provided by the ERP experiment.

The present facilitatory effect of syllable overlap is consistent with previous data found in English (Titone & Connine, 1997; Cutler & Chen, 1995; Burton, 1992; Corina, 1992; Emmorey, 1989). However, the finding that the rime effect is smaller than that of syllable overlap is in partial conflict with the data reported by Burton (1992) and Emmorey (1989). Using words with the STRONG–weak stress pattern that is most common in English, Emmorey (1989) found facilitation from syllable overlap but not rime overlap. By contrast, Burton (1992) obtained facilitatory effects of the same size for rime and syllable overlap. The absence of rime effect in Emmorey's (1989) study may be due to the fact that the rime was always an inflectional suffix. This was never the case in the present study or in Burton's (1992).

EXPERIMENT 2

Previous ERP studies by Radeau et al. (1998) and Praamstra and colleagues (Praamstra & Stegeman, 1993; Praamstra et al., 1994) have consistently shown that rime overlap between monosyllabic primes and targets is associated with a reduction in the auditory N400 amplitude. Experiment 2 was designed to study the ERP correlates of final overlap phonological priming between bisyllabic items, using the same spoken materials as in the unimodal auditory condition of Experiment 1. Participants performed a delayed lexical decision task that required response to pseudowords only (go/no-go nonword decision), so that ERPs to targets were not contaminated by motor-related processes.

ERPs were analyzed in order to track the time-course of phonological priming and to investigate the scalp distribution of these priming effects. Radeau et al.'s (1998) comparison of the ERP correlates of phonological and semantic priming found that the difference between phonological and semantic N400 effects tended to be larger at frontal sites. However, the small number of recording sites (9) in this previous experiment did not allow precise analyses of the scalp distribution of the N400 effects. To provide further insight into the spatial distribution of phonological priming, ERPs were recorded from 19 electrodes in the present study.

Results

General Analysis

General ANOVAs, including Overlap (coda, rime, syllable, and control), Lexicality (word and pseudoword), and Electrodes (17 levels) were performed in successive latency bands posttarget presentation. Results revealed that the main effects of Overlap, Lexicality, and Electrodes, as well as the interactions between the effects of these factors, were significant in the latency bands of interest (400–1000 and 1000–2000 msec). Therefore, separate analyses were conducted for word and pseudoword targets.

Word Targets

Figure 1 illustrates the ERPs recorded from midline sites, for word targets in the four overlap conditions: syllable, rime, coda, and control. ERP waveforms are perfectly superimposed in the 200 msec before target presentation. A P1–N1–P2 complex is then clearly identifiable at fronto-central sites between 50 and 400 msec postword onset. The amplitude of these components is not modulated by the degree of final overlap. By contrast, the amplitude of the N400 that develops between 400 and 1000 msec seems to be influenced by the degree of final overlap. A two-way ANOVA, including Overlap (coda, rime, syllable, and control) and Electrodes (17 levels)

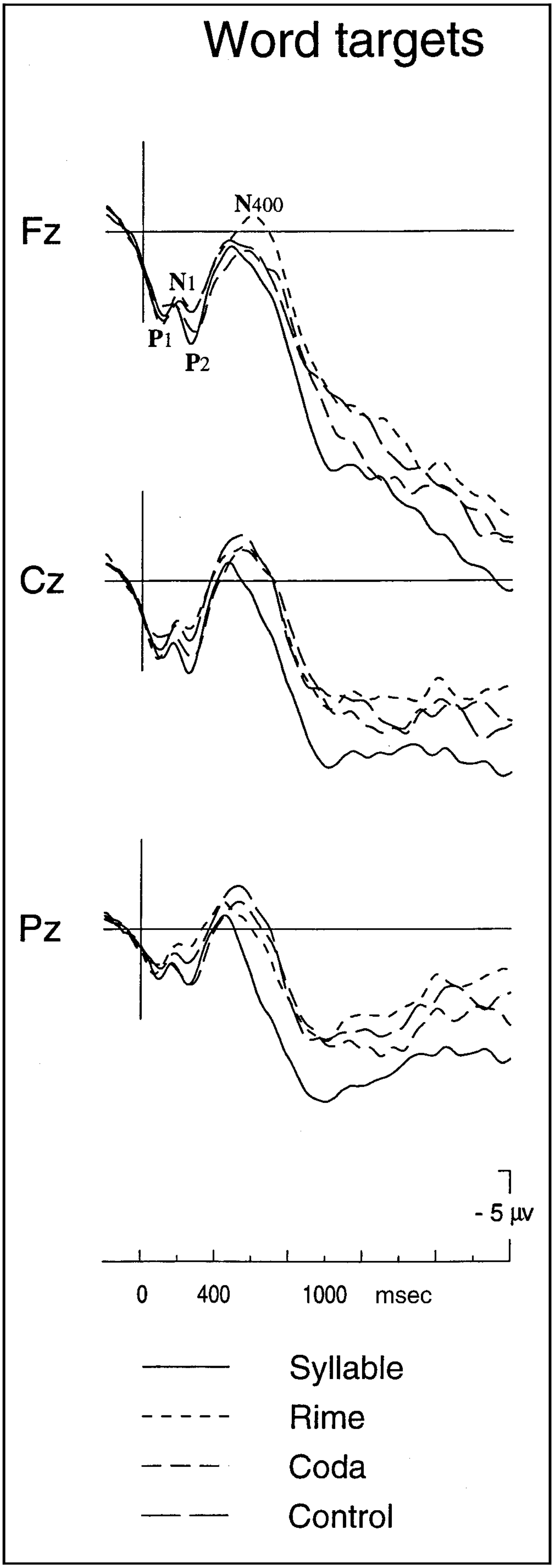


Figure 1. Grand average ERPs, over 17 participants, recorded from midline sites (Fz=Frontal, Cz=Central, and Pz=Parietal) and time-locked to target word onset in four experimental conditions: syllable overlap, rime overlap, coda overlap, or no overlap (controls) between primes and word targets. In this and subsequent figures, amplitude (µV) is represented on the ordinate, with negative voltage up, and time (msec) on the abscissa. The vertical bars indicate target-onset.

was conducted in the latency band in which the differences between overlap conditions were largest, that is the 400–1000 msec latency band. Results showed that the main effect of Overlap was indeed significant ($F(3, 48) = 4.13$, $MSE = 62.06$, $\epsilon = .59$, $p < .02$). Post hoc comparisons (Tukey, HSD) showed that the mean amplitude in the syllable condition (3.6 μV) was more positive than in the other three conditions that did not differ from one another (rime = 1.6 μV, coda= 2.2 μV, and control= 1.6 μV). Finally, results in the 1000–2000 msec latency band showed that the main effect of Overlap was also significant ($F(3, 48) = 5.68$, $MSE = 70.66$, $\epsilon = .79$, $p < .007$). Post hoc comparisons (Tukey, HSD) revealed that the mean amplitude was larger for the

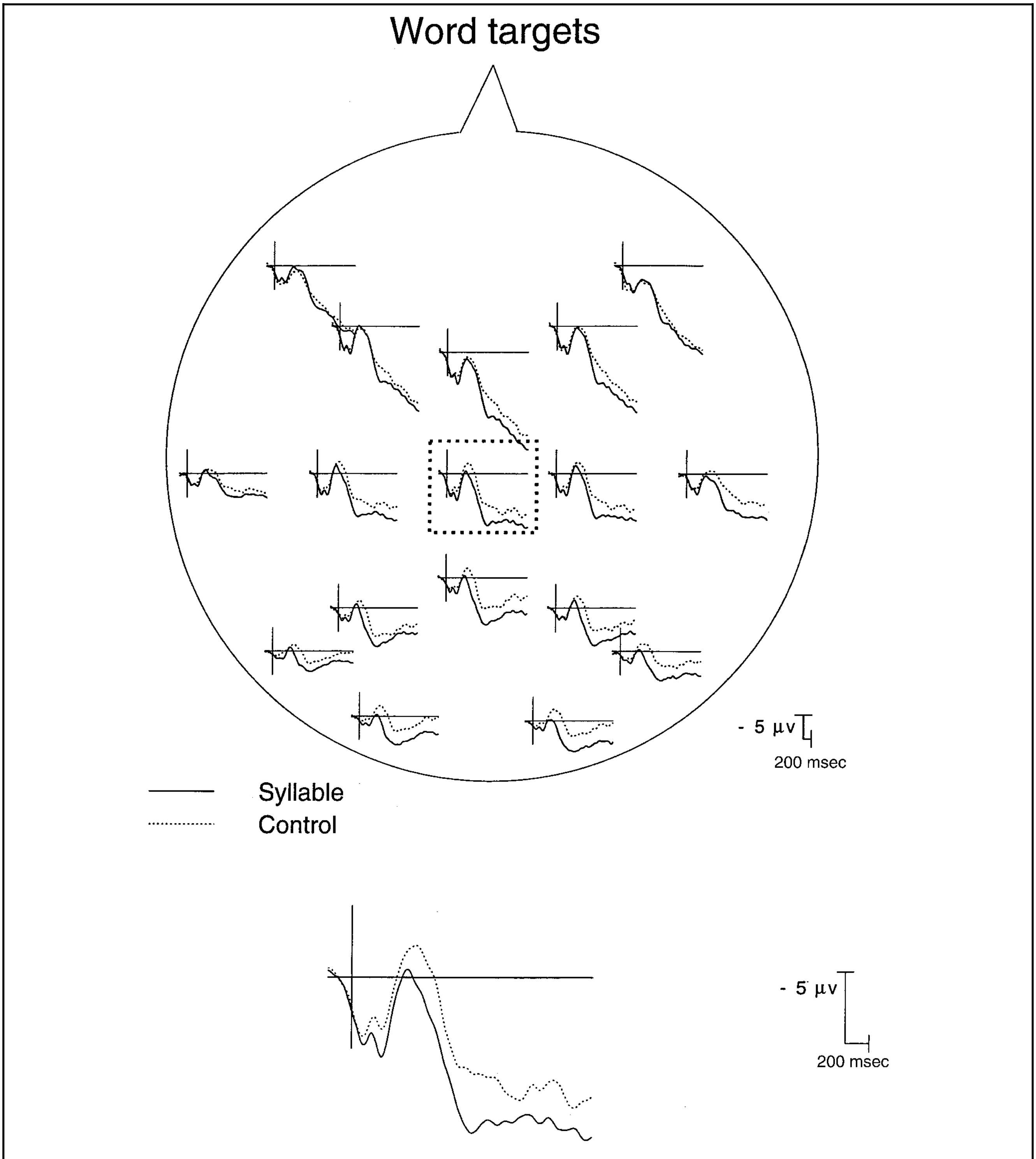


Figure 2. Overlapped are the ERPs to word targets in the syllable and control conditions recorded from 17 scalp sites. In this and subsequent figures, ERPs are recorded from 17 scalp sites and the recording from central site (Cz) is enlarged at the bottom of the figure.

syllable (8.9 μV) than for the other overlap conditions that did not differ from one another (rime = 6.2 μV; coda = 7.7 μV, and control = 6.7 μV). In order to further test these effects and their topographical distribution, each overlap condition was separately compared to the control condition, in both latency ranges of interest.

Syllable overlap. As can be seen in Figure 2, from around 100 msec to the end of the recording period, ERPs in the syllable condition were more positive than in the control condition. Results of two-way ANOVAs, including Overlap (syllable vs. control) and Electrodes (17 levels) as factors, showed that this difference was significant in the 400–1000 msec latency band ($F(1, 16) = 5.14$, $MSE = 115.13$, $p < .03$), with larger mean amplitude for syllable (3.6 μV) than control targets (1.6 μV). The interaction between the effects of Overlap and Electrodes was also significant ($F(16, 256) = 3.08$, $MSE = 3.52$, $\epsilon = .26$, $p < .02$). In order to further track this interaction,

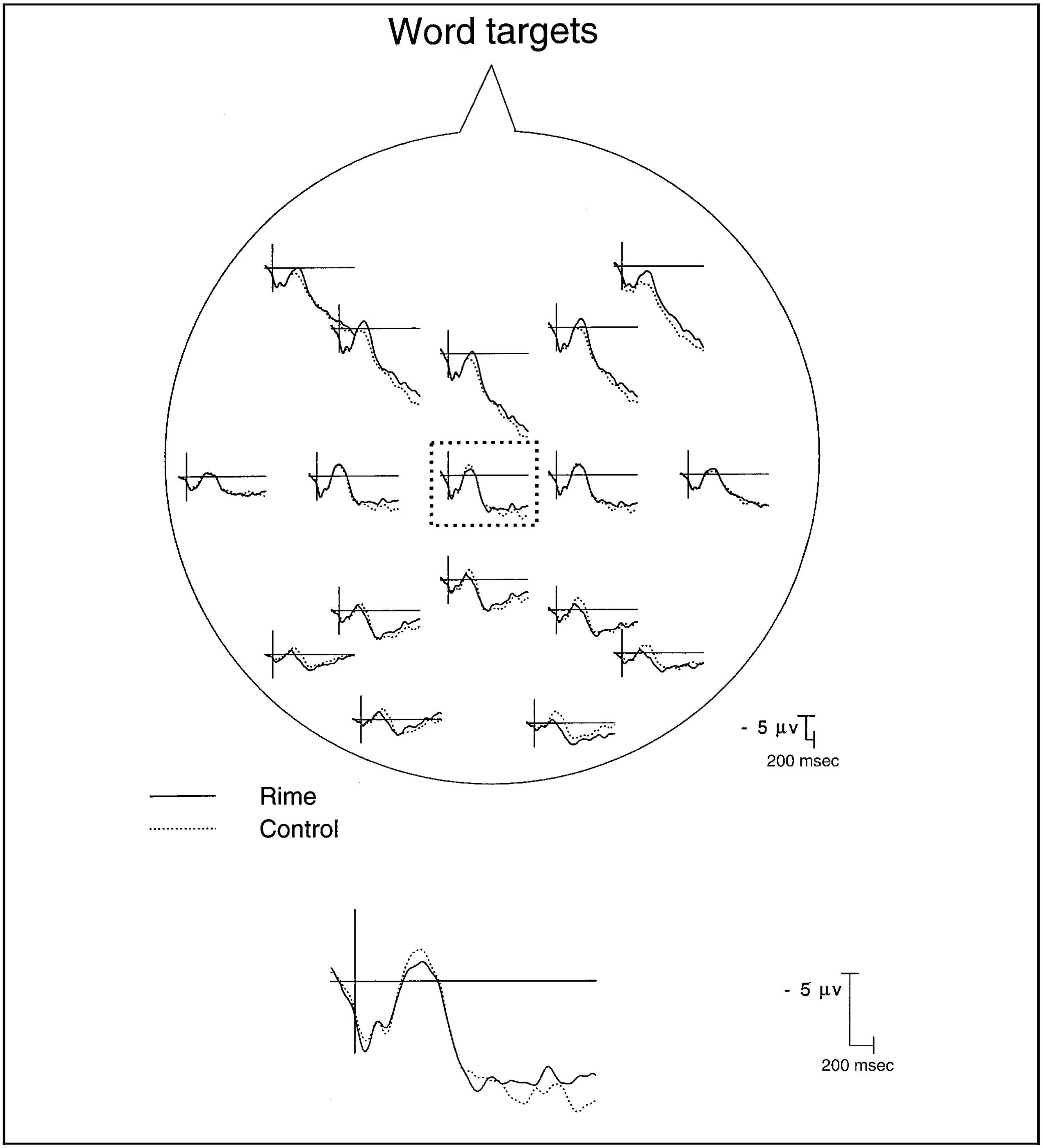


Figure 3. Overlapped are the ERPs to word targets in the rime and control conditions.

a three-way ANOVA including Overlap (syllable vs. control), anterior/posterior Locations ([F3–F4] vs. [C3–C4] vs. [P3–P4] vs. [F7–F8] vs. [T3–T4] vs. [T5–T6] vs. [O1–O2]), and Hemispheres (left vs. right) as factors was performed. Results showed that the effect of syllable overlap was larger over centro-temporo-posterior sites than over antero-frontal sites ($F(6, 96) = 4.59$, $MSE = 19.32$, $\epsilon = .22$, $p < .04$), with no difference between the right and left hemispheres. In the 1000–2000 msec latency band, the main effect of syllable overlap was significant ($F(1, 16) = 7.48$, $MSE = 88.25$, $p < .01$) with larger mean amplitude in the syllable (8.9 μV) than control conditions (6.7 μV). This effect did not vary as a function of electrode sites.

Rime overlap. Although the effect of Overlap is clearly smaller for rime than syllable, ERPs in the rime condition differ from the ERPs in the control condition (see Figure 3), with a slightly larger N400 in the rime than control

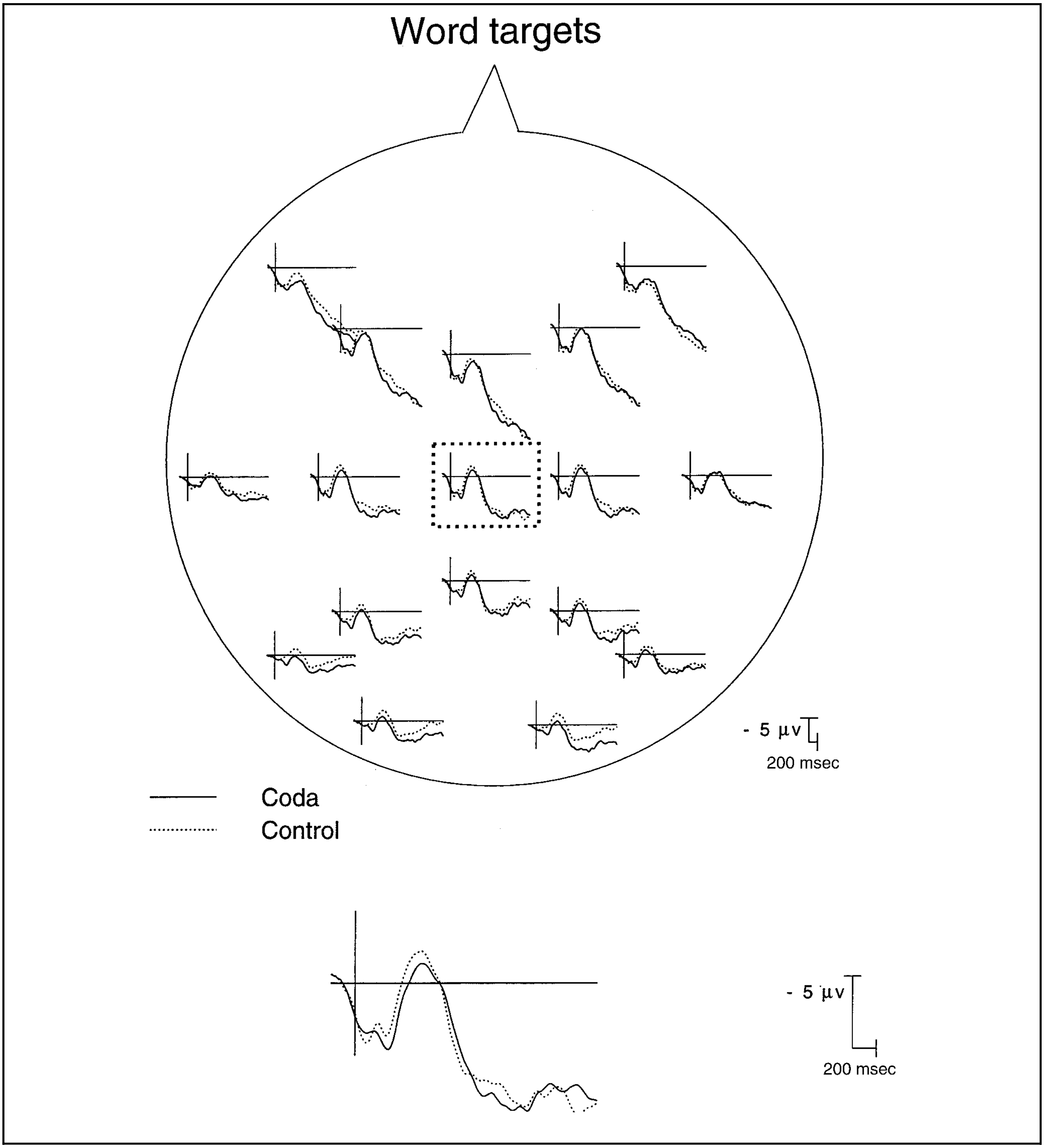
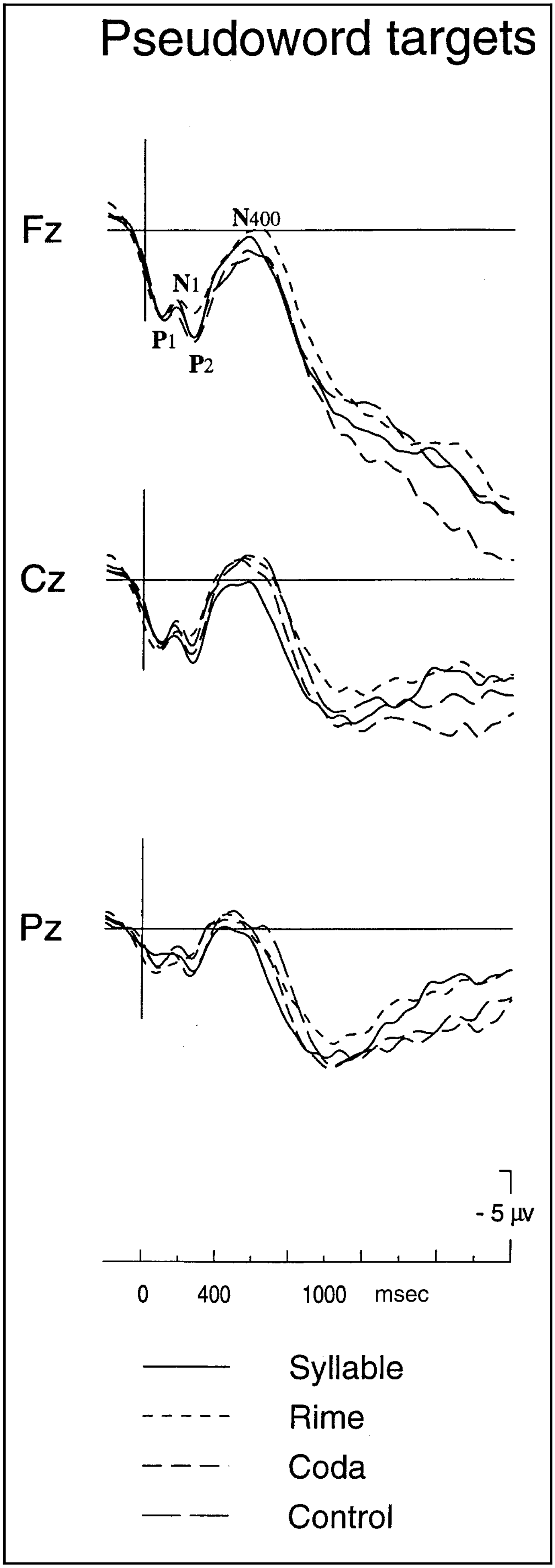


Figure 4. Overlapped are the ERPs to word targets in the coda and control conditions.



conditions at anterior frontal sites and a reverse effect at posterior sites. In the 400–1000 msec latency band, results of two-way ANOVAs, including Overlap (rime vs. control) and Electrodes (17 levels) as factors, showed no significant main effect of rime overlap ($F < 1$) but a significant rime by electrodes interaction ($F(16, 256) = 4.03$, $MSE = 3.01$, $\epsilon = .18$, $p < .01$): the mean amplitude in the N400 latency band was less positive in the rime (1.1 µV) than control (1.9 µV) conditions at anterior frontal sites, but was less positive in the control (0.1 µV) than rime (1.5 µV) conditions at posterior occipital sites. Separate ANOVAs were performed in the 400–1000 msec range that included Overlap anterior fronto-central Electrodes and hemispheres as factors. Results showed that ERPs in the rime condition did not significantly differ from the ERPs in the control condition ($p = .10$). By contrast, results of separate ANOVAs including only posterior temporal electrodes showed that this difference was significant ($F(3, 48) = 3.13$, $MSE = 2.54$, $\epsilon = .48$, $p < .03$), with no difference between left and right hemispheres. Neither the main effect of rime overlap nor the rime by electrode interaction were significant between 1000 and 2000 msec.

Coda overlap. As can be seen in Figure 4, the ERPs in the coda and control conditions do not seem to differ, except at occipito-posterior sites where ERPs in the coda condition were more positive than in the control condition, in the late portion of the waveform (1000–2000 msec). Results of the ANOVAs showed, however, that neither the main effect of Overlap nor the Overlap by Electrode interaction were significant ($p > .2$ in both cases).

Summary. For word targets, results showed a large phonological priming effect due to final syllable overlap with no trend to lateralization. This effect was significant from 400 msec after target onset until the end of the recording epoch, and was broadly distributed across scalp sites, with a slight prominence over posterior occipital regions. The effect of rime overlap was clearly smaller and more localized than the syllable effect. It was only significant in the 400–1000 msec latency band, over the posterior occipital regions, and although it appeared to be somewhat right-sided especially at these sites, no significant lateralization was obtained. Finally, there was no significant effect of coda overlap.

Pseudoword Targets

Figure 5 illustrates the ERPs recorded, from midline sites, for pseudoword targets in the four overlap conditions: syllable, rime, coda, and control. As noted for word targets, ERP waveforms are again perfectly superimposed

Figure 5. ERPs recorded from midline sites (Fz=Frontal, Cz=Central, and Pz=Parietal) and time-locked to target pseudoword onset in four experimental conditions: syllable overlap, rime overlap, coda overlap, or no overlap (controls) between primes and pseudoword targets.

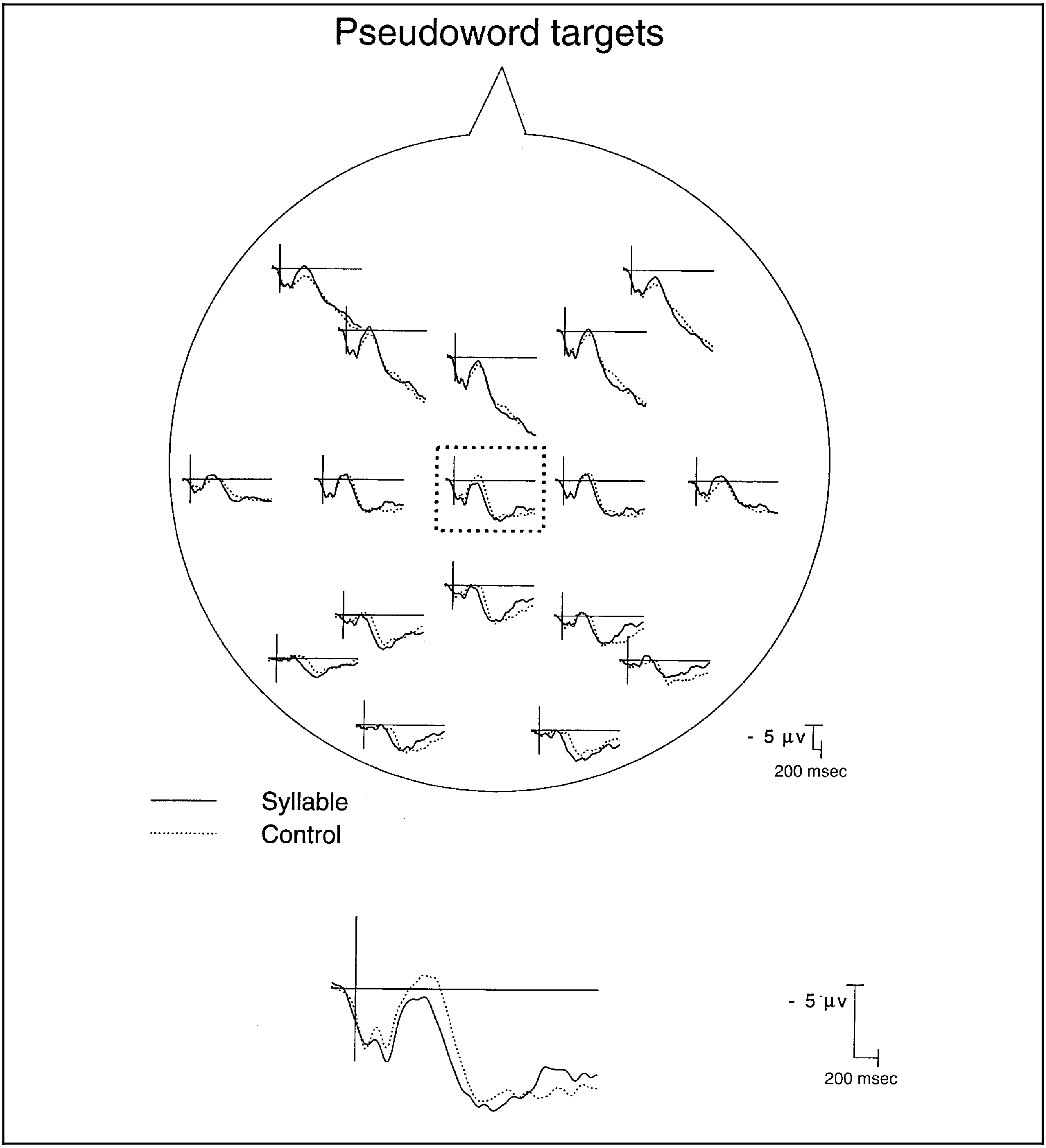


Figure 6. Overlapped are the ERPs to pseudoword targets in the syllable and control conditions. In this and subsequent figures, ERPs are recorded from 17 scalp sites and the recording from central site (Cz) is enlarged at the bottom of the figure.

in the 200 msec before target presentation. A P1–N1–P2 complex is then clearly identifiable at fronto-central sites between 50 and 400 msec postpseudoword onset. The amplitude of these components does not seem to be modulated by the degree of final overlap. In contrast, the amplitude of the N400 to pseudowords seems to be influenced by the degree of overlap, but to a lesser extent than for words. A two-way ANOVA, including Overlap (coda, rime, syllable, and control) and Electrodes (17 levels) in the 400–1000 msec latency band showed that the main effect of Overlap was not significant ($F < 1$), but the Overlap by Electrode interaction almost reached significance ($F(48, 768) = 1.99$, $MSE = 2.29$, $\epsilon = .14$, $p < .06$), and was significant in the 350–900 msec latency band[9]($F(48, 768) = 2.29$, $MSE = 2.14$, $\epsilon = .13$, $p < .03$). Finally, results in the 1000–2000 msec

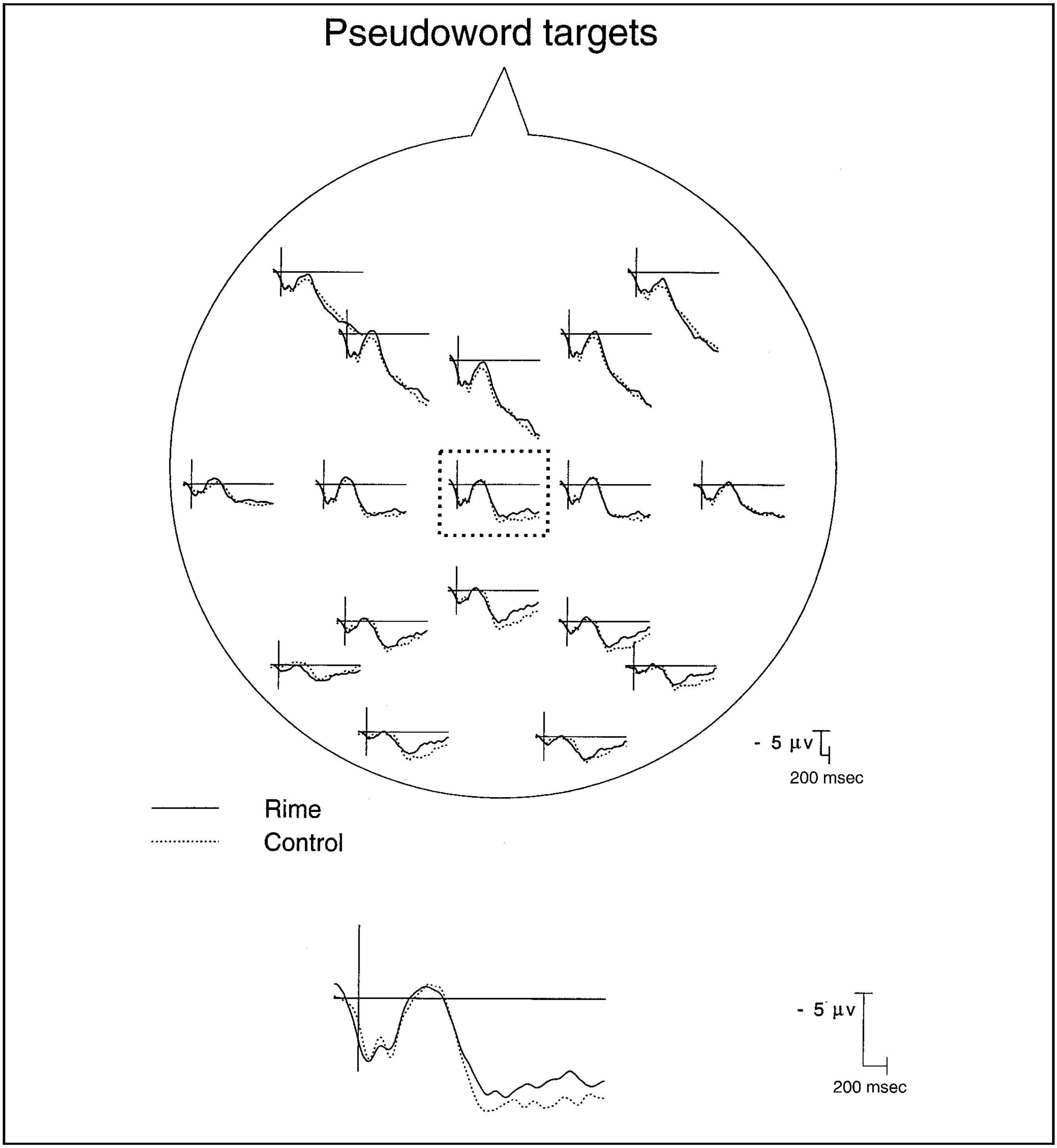


Figure 7. Overlapped are the ERPs to pseudoword targets in the rime and control conditions.

latency band showed that the main effect of Overlap was significant ($F(3, 48) = 2.89$, $MSE = 85.69$, $\epsilon = .97$, $p < .04$). Results of post hoc comparisons showed that the mean amplitude in the coda condition was larger (8.3 µV) than in the rime condition (rime = 6.2 µV) but did not differ from the other conditions (syllable = 6.5 µV and control = 6.7 µV). In order to further test these effects and their topographical distribution, each overlap condition was separately compared to the control condition, in both latency ranges of interest.

Syllable overlap. As can be seen on Figure 6, while the ERPs in the syllable and control conditions do not appear to differ for the entire recording period over anterior frontal and temporo-central regions, larger N400 components were elicited in the control than syllable conditions over parieto-occipital electrodes. Re-

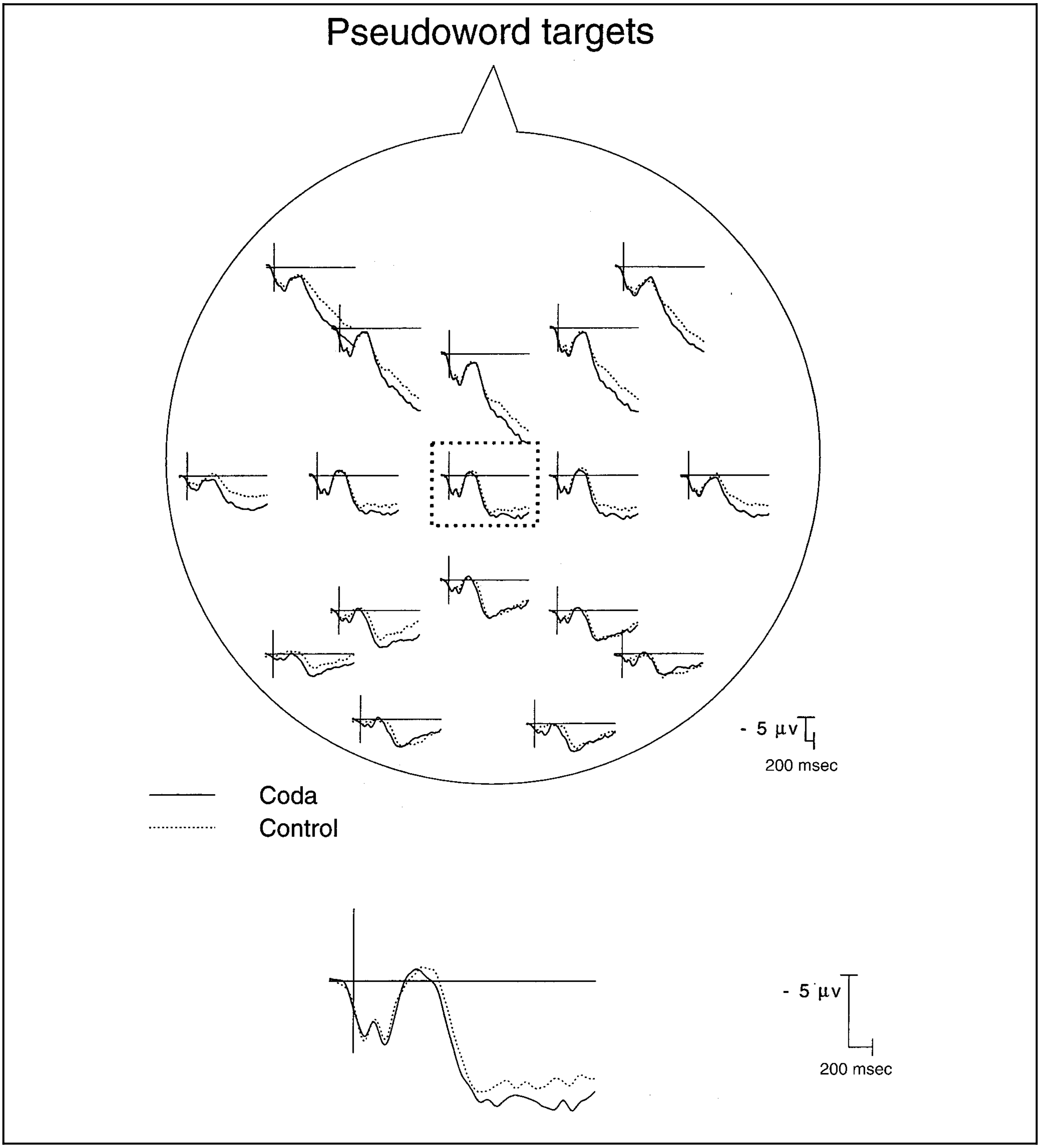


Figure 8. Overlapped are the ERPs to pseudoword targets in the coda and control conditions.

sults of two-way ANOVAs, including Overlap (syllable vs. control) and Electrodes (17 levels) as factors, confirmed a significant syllable overlap by electrode interaction in the 350–900 msec latency band ($F(16, 256) = 3.95$, $MSE = 2.56$, $\epsilon = .20$, $p < .01$). In order to further track this interaction, a three-way ANOVA including Overlap (syllable vs. control), anterior/posterior Locations, and Hemispheres (left vs. right) as factors was performed. Results showed that the difference between the syllable and control conditions was indeed larger over posterior than anterior regions ($F(6, 96) = 4.12$, $MSE = 3.88$, $\epsilon = .28$, $p < .02$). Finally, while at posterior sites the amplitude of the late positivity between 1000 and 2000 msec also seemed larger in the control than syllable conditions, this effect was not reliable ($p > .20$).

Rime overlap. ERPs to pseudowords in the control condition were slightly more positive than ERPs in the rime condition in the late portion of the waveform

(1000–2000 msec) at posterior sites (see Figure 7). However, results of ANOVAs including Overlap (rime vs. control) and Electrodes (17 levels) as factors showed no significant main effect of rime overlap ($F < 1$), nor any significant interaction in the 350–900, 400–1000 and 1000–2000 msec latency bands.

Coda overlap. As can be seen in Figure 8, ERPs in the coda and control conditions differed at fronto-anterior and central sites, where the ERPs to coda seemed more positive than in the control condition, in the late portion of the waveform (1000–2000 msec). Results of two-way ANOVAs including Overlap (coda vs. control) and Electrodes (17 levels) as factors confirmed the reliability of this effect, with a significant Overlap by Electrodes interaction ($F(16, 256) = 3.42$, $MSE = 3.79$, $\epsilon = .34$, $p < .004$). In order to further track this interaction, a three-way ANOVA including Overlap (coda vs. control), anterior/posterior Locations, and Hemispheres (left vs. right) as factors was performed in the 1000–2000 msec latency band. Results of this topographical analyses showed that the difference between coda and control was larger over fronto-anterior sites than centro-temporal and posterior sites ($F(6, 96) = 22.22$, $MSE = 47.34$, $\epsilon = .25$, $p < .0001$).

Summary. Results showed that phonological priming effects were much smaller for pseudoword than for word targets. The main effect found for pseudowords was due to syllable overlap, in the N400 latency band, over posterior regions. While no significant effect was found for rime overlap, a late frontally distributed effect was found for coda overlap.

GENERAL DISCUSSION

ERP results are in line with those found in the RT experiment. We found clear evidence for final phonological priming between spoken items: targets sharing the last syllable or the rime with the prime were associated with smaller N400s than targets in the coda or in the control conditions that did not differ from each other. Overall, these priming effects were larger over posterior regions, started around 400 msec posttarget onset and lasted until the end of the recording period (i.e., until 2000 msec posttarget onset). Of most interest, the analyses demonstrated that the effect of syllable overlap was of larger magnitude than that of rime overlap. Furthermore, both effects were larger for word than for pseudoword targets.

Taken together, these data extend previous findings of final overlap between monosyllabic items to bisyllabic items, using both RT and ERP measures, and two different tasks: single word shadowing and go/no-go delayed nonword decision (Radeau et al., 1994, 1995, 1998; Praamstra & Stegeman, 1993; Praamstra et al, 1994; Burton, 1992; Corina, 1992; Slowiaczek et al., 1987, 2000). For both rime and syllable overlap, facilitation was found on RTs, and a decrease was observed in the amplitude of the auditory N400. Furthermore, the effect of rime overlap lasted longer in the present experiment with bisyllabic items (it was significant between 400 and 1000 msec) than in the Radeau et al. (1998) experiment with monosyllabic items (it was significant between 450 and 700 msec). Thus, word duration clearly influenced the duration of rhyme priming.

The first aim of the present experiments was to study the representational basis of final phonological overlap priming. Of interest was to determine whether these effects were qualitative or quantitative in nature. We hypothesized that if specific linguistic units, such as the syllable or the rime, underlie the final phonological priming effects, facilitation should be found for one of these units, or both, but not for coda overlap. In contrast, if the amount of shared acoustic–phonetic information plays a crucial role, a linear relationship between facilitation and number of shared phonemes should be found.

Both RT and ERP results showed final phonological overlap priming effects. Furthermore, facilitatory effects on both measures were larger for syllable than rime overlap and no effects were found for coda overlap. It thus appears that rime overlap and syllable overlap contribute, differentially however, to the effect of final phonological similarity.

Interestingly, some differences also emerged in the ERP phonological priming effects due to these two linguistic units. For words, the effect of syllable overlap was larger and more extended (it was significant in both latency bands, 400–1000 and 1000–2000 msec, of interest) than the effect of rime overlap, that was restricted to the first latency range. Moreover, rime overlap priming seemed more localized, over the temporo-posterior sites, than syllable overlap priming, largely distributed across the scalp (see Figures 2 and 3). The finding of effects that are temporally and spatially more localized for rime than for syllable overlap may suggest that these effects involved distinct rime and syllable representations per se, an interpretation that of course needs further support. These results are mainly descriptive, and further experiments will be dedicated to localizing syllable and rime overlap effects using functional Magnetic Resonance Imaging.

Another way to gain further clues to the representational issue consists in comparing the CVC syllable overlap effect with the effect produced by a similar overlap that would not, however, correspond to a final syllable. Such a direct comparison involving bisyllabic items has not yet been undertaken experimentally. Nevertheless, indications can be found by comparing our results to those of experiments using monosyllabic items. In an experiment performed by Radeau (1995) on CCVC items, a CVC overlap was used that corresponded to no particular linguistic unit except that it included the rime (e.g., vrac–trac). The effect produced by such a nonsyllabic CVC overlap was not larger than the rime effect (e.g., flaque–trac). The fact that, in the present experiment, a CVC overlap matched with a syllable gave rise to an effect greater than that of the rime, while a CVC overlap not matched with a syllable did not in Radeau's (1995) study, suggests that syllables per se may mediate final phonological priming in multisyllabic items. This conclusion is also consistent with Titone and Connine's (1997) results, showing that final phonological priming is sensitive to item syllabification (see Introduction). Further evidence is clearly necessary to substantiate the role of syllables in phonological priming.

Our finding of significant effects of final overlap for word items stands in contrast with the results reported by Van Petten, Coulson, Rubin, Plante, and Parks (1999), using the N400 semantic congruity effect in sentential context as an index of phonological priming. These authors found no decrease in N400 amplitude when the sentence final word was not expected within the context but nevertheless rhymed with the expected completion (e.g., "The main highway was flooded so they had to take a long contour"—rhyming with "detour"). A possible explanation we propose for the lack of rhyme priming effect in this particular situation is that the target ("detour" in the above-example) was never physically presented but could just be described in terms of a silent mental item. It is thus possible that, in the absence of real auditory presentation of the target, the processing system was given no opportunity to benefit from the primed common representational form that seems, according to our RT and ERP results, to underlie final overlap priming effects in nonmetaphonological tasks (i.e., shadowing and lexical decision). As Van Petten et al. (1999, p. 412) have themselves suggested, their "auditory–mind" priming paradigm might have presumably needed the full engagement of the participants in an explicit rhyme detection task to finally elicit N400 rhyme effects, as is the case in the visual modality (Kramer & Donchin, 1987; Polish et al., 1983; see also the discussion by Kutas & Van Petten, 1988, pp. 176–179). Such an interpretation may also explain the absence of effect in crossmodal situations, either with visual primes and auditory targets as in Experiment 1 and in Radeau (1995), or the reverse (Cutler et al., 1999; Radeau et al., 1994). Indeed, the lexical decision and the shadowing tasks performed in these experiments do never require the phonological recoding of the visual prime (or target) item. The present final phonological similarity effect is limited to the auditory modality: the representation involved in final priming has to be "heard" and "re-heard" to get an effect.

The second aim of the present experiments was to examine the effect of target lexicality on final phonological priming. One possible explanation for final overlap effects is that priming occurs during the lexical selection phase of word recognition. More precisely, the representation activated by the final information in the prime may subsequently be used to reduce the target cohort (Radeau et al., 1995). According to such a hypothesis, only words—that are stored in the lexicon—but not pseudowords—that are not—should show phonological facilitation. However, both the RT and ERP results showed priming effects not only for words but also, though they were of smaller size, for pseudowords. These results for pseudowords clearly allow rejection of the idea that priming arises during target selection only. Hence, if final priming is due to a single mechanism, it is simply not the one just described. Nevertheless, it is difficult to envisage a single mechanism that can explain both the effect on nonstored items, and the larger priming effect on words than on pseudowords.

The present priming pattern might also result from the joint involvement of several mechanisms: one mechanism, applying to both words and pseudowords, could explain the substantial effect on pseudowords as well as a part of the effect on words; the other mechanism would account for the additional priming effect found on words. This latter may well be the mechanism occurring during target lexical selection (described above) that remains a good explanation for the additional priming on words. As regards the part of the effect that is not specific to words, there are at least two possible explanations. As we used long items, in which the final syllable sometimes constitutes a word, a mechanism of lexical activation may still have influenced the processing of pseudoword targets. Indeed, lexical activation has been demonstrated for an embedded word that matches the final syllable of a longer item, such as the word "bone" in "trombone" (Shillcock, 1990; see also Content, Dumay, & Frauenfelder, 2000; Luce & Cluff, 1998; Vroomen & de Gelder, 1997; Cluff & Luce, 1990). This phenomenon makes clear predictions as regards the present study. No priming effect should be observed on words and pseudowords in which the final syllable is not a word (e.g., the final syllable of "timide" is not a word). A post hoc analysis was therefore carried out on the RTs to pseudowords in the syllable overlap condition of the unimodal part of Experiment 1. Thirty-one pseudoword targets had a word as final syllable (e.g., pa.luge in which "luge" is a French word), while 49 pseudowords had not (e.g., pé.cove in which "cove" is not a French word). The analysis showed that the syllable overlap effect was not significantly modulated by the lexicality of the final syllable embedded in the target. The effects were not different for targets with a word (36 msec) or a pseudoword (29 msec) as final syllable ($F1 < 1$). Such results clearly cast doubt on the explanation of the present priming effects for pseudowords in terms of the "bone" in "trombone" lexical activation phenomenon. They rather suggest that the part of the priming effect that is not specific to words, it is due to a nonlexical mechanism unaffected by the lexicality of the shared speech sequence. One possibility is that intermediate representations already activated or computed during prime processing would be more rapidly available for target identification. In sum, a nonlexical mechanism would explain the effect on pseudowords and a part of the effect on words, while a lexical selection mechanism would account specifically for the additional priming on words.

Finally, we were also interested in studying the scalp distribution of the final phonological priming effect more precisely than was possible in our previous experiment (Radeau et al., 1998). For words, two distinct effects can be dissociated on the basis of their temporo-spatial distribution: one on the N400 component (in the 400–1000 msec range), and the other on the late positivity in the 1000–2000 msec latency band. The first effect is significant for both the syllable and rime overlap although it takes a somewhat different form in both cases. For syllable overlap, the N400 is smaller than in the control condition. This decrease in N400 amplitude, while largely distributed, is larger over centro-temporo-posterior regions of the scalp than over the antero-frontal regions. For rime overlap, the pattern is more complex, with an increase in N400 amplitude in the rime compared to the control condition at antero-frontal sites, no difference between the two conditions over temporo-central sites, and a decrease in N400 amplitude in the rime compared to the control condition over posterior occipital regions. The second effect on words, in the 1000–2000 msec range, was only significant for syllable with an increased long-lasting positivity for syllable compared to control. This late effect was equally distributed across scalp sites.

These findings are in line with our previous results showing that N400 rime effects were larger over posterior than frontal regions (Radeau et al., 1998). They also fit well with those of PET studies of speech processing (see the recent review by Price, Indefrey, & Van Turennout, 1999). As shown by Zatorre, Meyer, Gjedde, and Evans (1996), the intentional analysis of phonetic segments of speech is generally associated with specific activation in the left frontal cortex, including a portion of Broca's area (Démonet et al., 1992; Zatorre et al., 1992, 1996). By contrast, the automatic perceptual phonological processing involved in listening to speech was found to be specifically carried out in the left posterior temporal or temporo-parietal region (Price et al., 1996; Zatorre et al., 1992, 1996; Wise et al., 1991; Petersen et al., 1988; for similar findings with fMRI, see also Binder et al., 1997, 1994). The present evidence for larger N400 effects over posterior than frontal areas is thus quite consistent with the available brain imaging data.

For pseudowords, effects were much smaller than for words, and, aside from a late effect for coda, difficult to interpret other than in terms of noise, they were only significant for syllable overlap. Interestingly, the scalp distribution of the pseudoword syllabic effect was similar to the distribution found for words, which again argues for the functional similarity of the effects found in both cases.

In the visual modality, N400 effects produced by linguistic materials show a significant paradoxical right-lateralization, reflecting presumably the greater involvement of the contralateral left hemisphere (Kutas, Hillyard, & Gazzaniga, 1988; see also the discussion by Van Petten & Rheinfelder, 1995). This right-sided asymmetry is massive and systematic in the rhyme-matching tasks (Barrett & Rugg, 1989; Rugg, 1984a, 1984b; Rugg & Barrett, 1987), and slightly smaller in the field of semantic congruency, where most of the time it is also found (see, for instance, the meta-analysis by Kutas, Van Petten, & Besson, 1988). The present auditory N400 syllable and rime effects clearly do not exhibit such a significant and substantial inter-hemispheric asymmetry, but just a nonsignificant trend to right-lateralization in the posterior occipital region for rime overlap on words (see Figure 3). A far less apparent paradoxical lateralization, never statistically significant, appears in fact an unconditional contrasting feature of N400 effects in spoken (compared to written) words, even when as in the present experiment potential biases like participant- and family-handedness (see Kutas, Hillyard, et al., 1988, Kutas, Van Petten, et al., 1988) are controlled for (e.g., Besson et al., 1997; Van Petten & Rheinfelder, 1995; Bentin et al., 1993; Praamstra & Stegeman, 1993; Praamstra et al., 1994). The scalp distributions reported in this paper thus indicate statistically equal contributions of the hemispheres to final phonological priming N400 effects. They also provide further evidence that N400 modulations are highly sensitive to the modality of the linguistic input.

The most remarkable property of the paradigm we used is that phonological priming may serve to describe the functional role of sublexical representations in spoken word recognition, without any requirement that the listener's attention be allocated to any particular sublexical level. However, any conclusive answer to the representation issue requires comparison of final overlap conditions of similar phonemic length but corresponding to different linguistic units, combined with the study of particular linguistic units (e.g., rime, syllable) unconfounded with overlap. As the use of a particular representation at a particular processing stage may in addition depend on the phonological properties of the listener's language (Kolinsky, 1998; Cutler, 1993; among others), the language-specific nature of the representations involved in priming will then also have to be assessed.

METHODS

Experiment 1

Participants

A total of 96 university students (18 men and 78 women; mean age: 20 years old; range: 18–31) participated in the experiment as volunteers or as part of an introductory psychology course. Half of the participants were tested under unimodal presentation, while the other half were tested under crossmodal presentation. All the participants were native speakers of French and reported neither hearing nor reading disorders.

Condition 1: Unimodal Presentation

Materials. The complete set of materials—experimental and filler—consisted of 500 pairs comprising a pseudoword prime, and a word or pseudoword target. All the items were bisyllabic and had a CV.CVC phonological structure. Because most of the available familiar words with such a structure were used as targets, only pseudowords remained as possible primes. The words were selected using BRULEX, a lexical database for French (Content, Mousty, & Radeau, 1990). A total of 80 words and 80 pseudowords were selected as experimental targets (see Appendix A). For each target (e.g., tirage), four pseudoword primes were created according to French phonotactic rules in such a way that prime and target shared the last phoneme (coda condition: lusoge), the last two phonemes (rime condition: lubage), the last three phonemes (syllable condition: lurage), or no final phonemes (control condition: lusole). The first syllable was the same for all four primes (lu, in the above example) so that priming conditions were comparable in initial overlap. Three hundred and forty pairs of items were used as fillers. They all consisted of a pseudoword prime and a word target with no common phonemes. Because of the high proportion of pseudowords in the experiment materials—all the primes and 50% of the experimental targets were pseudowords—we used only words as filler targets to discourage participants from engaging in purely nonlexical processing. All the targets, experimental and fillers, began with a stop consonant.

The acoustical duration of the experimental items was measured after digitization. Mean length was 739 msec (range: 582–940) for word targets. For the corresponding primes, it was 849 msec (range: 712–1010) in the control condition, 845 msec (range: 660–976) in the coda condition, 871 msec (range: 610–1060) in the rime condition, and 840 msec (range: 624–1040) in the syllable condition. For the pseudoword targets, mean length was 766 msec (range: 628–920). For the corresponding primes, it was 807 msec (range: 648–992) in the control condition, 820 msec (range: 628–992) in the coda condition, 836 msec (range: 668–1040) in the rime condition, and 829 msec (range: 644–960) in the syllable condition.

Four lists of 500 trials were constructed, each including 160 experimental trials and 340 filler trials. Each of the 80 word targets and 80 pseudoword targets were paired with one of the four corresponding primes, so that an item never appeared more than once in a list and that the eight within-subject experimental conditions (four prime types × two lexical status of the target) were equiprobably represented. The position of the filler trials, as well as that of the experimental targets, were common across the lists. Each list was split into four balanced blocks of trials. In each block, the proportion of related trials was 24%. The order of stimulus presentation was determined pseudo-randomly, with the constraint that an experimental or filler trial did not occur more than three times consecutively, and that the same condition never occurred in more than three subsequent experimental trials.

Procedure. The 1480 items (160 targets + [4 × 160 primes] + [2 × 340 fillers]) were recorded by a male native speaker of French in a soundproof room on a Panasonic digital-audiotape recorder SV-3700 via a Neumann U-87 microphone. They were then digitized at a sampling rate of 32 kHz with 16-bit analog-to-digital conversion, using the Sound Tools editor software on a Macintosh Si computer.

The stimuli were transferred to the left channel of a digital-audiotape using a Sony 60ES digital-to-analog converter. They were stored as pairs of corresponding primes and targets with a 5-sec interval between the primes of two consecutive pairs. The ISI between the offset of the prime and the onset of the target within each pair was 20 msec. A square wave click, inaudible to the participant, was stored on the right channel 20 msec before the onset of each target, and triggered a voice key connected to a clock-card (Apple Clock Mountain Hardware). Presentation of the items and data collection were controlled by an Apple IIe computer connected to the D/A converter. The stimuli were presented at a comfortable level through a pair of Beyer DT-202 headphones connected to the left channel of the D/A converter. The participants were tested individually in a quiet room. The experimental task was target shadowing: participants were required to repeat back the second item of each pair as quickly and accurately as possible. A voice key detected the participant's response and cut off the clock card.

Twelve participants were assigned to each of the four lists. The order of presentation was varied so that half of the participants were presented with blocks 1, 2, 3, and 4, and the other half with blocks 3, 4, 1, and 2. There was a 2-min break between blocks of trials. The session started with a practice block using similar materials to familiarize the participant with the task. The experiment lasted about an hour. At the end of the session, participants were asked if they had noticed any phonological relation between primes and targets.

Condition 2: Crossmodal Presentation

The experimental task was still target shadowing. Materials and procedure were the same as in the unimodal condition, except that printed primes were used. Because all the primes were pseudowords, their orthographic form was constructed following a set of rules.

Prime and target within a given pair had the same number of letters and the same consonant–vowel pattern, except for some vocalic digraphs in which two letters stand for only one phoneme (e.g., "en" in French). Moreover, each digraph in a target corresponded to another digraph in its prime (e.g., cagoule was preceded by mérenle as prime in the coda condition). Phonemes whose spelling had more than one reading were avoided.

Visual presentation of the primes required control of participants' attention because without a requirement to process the prime the participant could look elsewhere or even close his/her eyes. Catch-trials were therefore included in filler trials. In these trials, two letters of the prime were replaced by the nonalphabetical $ sign to be detected by the participants, as secondary task. There were 6.4% of catch trials (eight in each block). The participants had to report that they had detected the nonalphabetical signs by saying "false" after having repeated the auditory target.

As in Condition 1, the auditory targets were transferred to the left channel of a digital-audiotape by means of a Sony 60ES D/A converter. A 20-msec square wave click, starting before target onset and used for timing purposes, was again stored on the right channel of the digital audiotape. Another 50-msec square wave click was also stored on the right channel, 800 msec before target onset that served to trigger the prime visual presentation. Both clicks were inaudible to the participant. The 800 msec asynchrony between prime and target onsets represented roughly the mean duration of an auditory prime in the unimodal condition (796 msec). The visual prime was presented for 600 msec, followed by a 200-msec blank. The time interval between the primes of two consecutive pairs was 5 sec. Presentation of the items and data collection were controlled by a Highscreen Pentium 120 MHz computer connected to a Sony 60ES D/A converter, using Micro Experimental Laboratory (M.E.L.) software. The visual primes appeared in white lowercase letters (text font) in the center of a black 14-inch screen at a distance of 30 cm from the participant's eyes.

Experiment 2

Participants

A total of 17 students (9 women; age range: 17–27, mean = 22 years), native speakers of French were paid to take part in the experiment, for roughly 2 hr. All were right-handers with no left-handed relatives. They were neurologically normal, and had normal hearing and normal or corrected to normal vision.

Materials

The same stimuli were used as in the unimodal condition of Experiment 1.

Design and Procedure

As for the RT experiment, the prime and target stimuli were played at a comfortable intensity level through headphones connected to the left channel of a D/A converter. The experiment was controlled by a Compaq 486 computer. Participants were instructed to keep their eyes open and to fixate on a dot on a computer screen situated in front of them. In contrast with the RT experiment, however, the task was a delayed lexical decision with manual response to pseudoword targets only. A tone was presented 2000 msec after target onset, and indicated to the participants that they could give their response and blink. This delayed procedure was used to avoid contamination of the ERPs of interest by motor-related potentials associated with response preparation and execution. Moreover, it ensured that participants were actively engaged in the task, as revealed by the high percentage of correct responses (89%).

Recordings

EEG was recorded for 2200 msec from 19 scalp electrodes mounted in an elastic cap, located at standard left and right hemisphere positions over frontal, central, parietal, occipital, and temporal areas (International 10/20 system sites Fz, Cz, Pz, Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6; Jasper, 1958). These recording sites were referenced to the left mastoid electrode. Impedances never exceeded 3 kΩ. The horizontal electro-occulogram (EOG) was recorded from a bipolar montage with electrodes over the left and right external canthi, and the vertical EOG was recorded from an electrode beneath the right eye, referenced to the left mastoid, to detect blinks and vertical eye movements. Trials containing occular artefacts, movement artefacts, or amplifier saturation were excluded from the averages using computer algorithms to reject trials in which values exceeded individually adjusted threshold. These automatically rejected trials were also checked visually by one of the experimenter for agreement. The rejection rate ranged between 11% and 18% across participants. The EEG and EOG were amplified by SA instrumentation amplifiers with a bandpass of 0.01–30 Hz, and were digitized at a 250 Hz sampling rate.

Data Analysis

ERPs were time-locked to the onset of the target stimulus and averaged off-line for a 2000-msec epoch, within each condition for each participant. Two electrode sites, Fp1 and Fp2, were not included in the analyses because large positive shifts, not representative of the effects seen at the other sites, were present at these two sites. ERP data were analyzed by computing the mean amplitude in selected latency windows relative to a 200-msec prestimulus baseline. Repeated-measure analyses of variance (ANOVAs) were carried out with the Greenhouse–Geisser correction for nonhomogeneity of variance applied when appropriate; reported are the uncorrected degrees of freedom, the ϵ value, and probability level following correction. Unless specified, Tukey (HSD) tests were used to test the significance of post hoc comparisons.

APPENDIX A. EXPERIMENTAL TARGETS

80 Words		80 Pseudowords	
bagage	dimanche	badète	gaduse
balade	divine	badote	gapite
baleine	docile	bafite	gobate
banane	domaine	bagète	gopive
baraque	dopage	bagole	govice
baroque	galère	balode	gupite
bavure	gamine	bapote	pacole
bazar	garage	bélige	paluge
bêtise	gazette	béline	pécove
bidule	godasse	béroce	pédule
bipède	guitare	bigate	pégate
bitume	panade	bivute	pélide
bobine	panique	bolute	pélogue
bolide	parade	bosine	pibafe
boutique	parole	botade	pibute
cabine	patate	botuge	pigote
cagoule	pelote	bovare	pimade
caniche	pelouse	bucide	pimette
capote	peluche	bugote	pisude
capuche	pelure	burave	pitave
carotte	pénal	cafore	pocute
cassette	pendule	camoge	podiche
colère	pépite	cobage	pomude
collage	pétale	colobe	porète
colline	pilote	comade	posine
comète	pilule	copate	pulète
compote	pirate	copide	pusate
copine	pirogue	corate	talade
coupure	police	cotine	tanège
courage	potage	coture	tarique
culotte	punaise	covèse	tidume
dédale	timide	danoche	tinuque
délice	tirade	dapute	tipage
délire	tirage	décote	tobène
déluge	tisane	détute	tobile
dérive	tonique	dimique	todule
déroute	tulipe	docane	tolime
désir	tunique	docète	topule
devise	typique	durique	tuloche

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Notes

1. Note that the term ''rime'' should not be confounded with the term ''rhyme'' used in poetry when the same final sound sequence reoccurs across words. The rhyming sound sequence includes at least the last rime of the word but may also consist in a larger part. Thus, items as contour and detour do rhyme by the final syllable.
2. ''Onset'' is the term used in phonology to refer to the optional consonant(s) that occur before the vowel in a syllable. Onset and rime are thus complementary parts of a syllable.
3. In the study performed by Titone and Connine (1997), the primary stress always fell on the first syllable, as in most English words.
4. In the sequence detection task, the participant is required to detect as quickly as possible CV or CVC speech sequences in carrier words of which the first syllable does or does not match the target. In French, the detection times were shown to be faster when the target matched the first syllable of the carrier word (e.g., ''pa'' in ''pa.lace'' or ''pal'' in ''pal.mier'') than when it did not (e.g., ''pa'' in ''pal.mier'' or ''pal'' in ''pa.lace''), resulting in the well-known ''syllabic effect.''
5. In phoneme monitoring, the syllabic effect is reflected in slower detection of the initial phoneme of a carrier syllable as the complexity of this syllable increases (CV < CVC < CCV).
6. In the attentional allocation paradigm, the participant is required to detect, as quickly as possible, phonemic targets in bisyllabic items. The statistical regularities of the materials enhance detection speed for a particular syllabic assignment of a given phonemic position (e.g., coda assignment of the third serial position, as ''c'' in tac.tile). The syllabic effect consists in that speed enhancement does not generalize to another syllabic assignment of that same given phonemic position (e.g., onset assignment of the third serial position, as ''b'' in ta.bleau).

7. In the phonological migration paradigm, the participant is dichotomically presented with two pseudowords (e.g., botou and kijon) selected so that complementary information parts can "migrate" and recombine into an illusory word [bijou (jewel) or koton (cotton)]. In French, the migration rate is higher when the complementary parts correspond to syllables ([biton] and [cojou]) than when they do not (e.g., [kijon] and [botou]).
8. In the word-spotting task, the participant is presented with nonce speech strings, and required to press a button whenever he or she hears a word embedded in a string and to repeat that word aloud immediately after. The spotting performance is sensitive to the carrier's syllabification. Words are easier to spot when their onset is aligned with the onset of a syllable (e.g. lac (lack) in zun.lac) than when not (zu.glac).
9. Subsequent analyses were therefore performed in the 350-900 msec latency band rather than in the 400-1000 msec range.

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