Neurophysiological Manifestations of Phonological Processing: Latency Variation of a Negative ERP Component Timelocked to Phonological Mismatch

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Abstract

■ Two experiments examined phonological priming effects on reaction times, error rates, and event-related brain potential (ERP) measures in an auditory lexical decision task. In Experiment 1 related prime-target pairs rhymed, and in Experiment 2 they alliterated (i.e., shared the consonantal onset and vowel). Event-related potentials were recorded in a delayed response task. Reaction times and error rates were obtained both for the delayed and an immediate response task. The behavioral data of Experiment 1 provided evidence for phonological facilitation of word, but not of nonword decisions. The brain potentials were more negative to unrelated than to rhyming word–word pairs between 450 and 700 msec after target onset. This negative enhancement was not present for word–nonword pairs. Thus, the ERP results match the behavioral data. The behavioral data of Experiment 2 provided no evidence for phonological facilitation. However, between 250 and 450 msec after target onset, i.e., considerably earlier than in Experiment 1, brain potentials were more negative for unrelated than for alliterating word–word and word–nonword pairs. It is argued that the ERP effects in the two experiments could be modulations of the same underlying component, possibly the N400. The difference in the timing of the effects is likely to be due to the fact that the shared segments in related stimulus pairs appeared in different word positions in the two experiments. ■

INTRODUCTION

The registration of brain electrical activity in human subjects engaged in linguistic tasks has revealed the existence of an event-related component associated with semantic processing. This brain potential, the so-called N400, was first described as a late negative wave elicited by visually presented sentence-final words that were semantically incongruent with the content of the sentence (Kutas & Hillyard, 1980a,b). Subsequent studies have provided further evidence that the N400 is sensitive to the degree of semantic association between a word and the context established by a preceding sentence (Kutas & Hillyard, 1984; Kutas, Lindamood, & Hillyard, 1984). Effects on the N400 can be observed in a number of different tasks. Experimental manipulations yielding N400 effects include, for instance, tasks involving the presentation of word pairs, such as the primed lexical decision task. In primed lexical decision experiments, targets preceded by semantically related primes typically elicit an N400 of smaller amplitude than targets preceded by unrelated primes (Bentin, McCarthy, & Wood, 1985; Holcomb, 1988; Holcomb & Neville, 1990; Rugg, 1985). Although these studies show that the N400 is sensitive to processes involved in the understanding of words, there is still considerable debate as to which processes these are (e.g., Brown & Hagoort, 1993; Holcomb, 1993; Kutas & Hillyard, 1989).

The N400 is not exclusively related to semantic processing. In a rhyme-judgment task for pairs of visually presented words or nonwords, unrelated stimuli elicit a negative wave of higher amplitude than rhyming stimuli (Rugg, 1984a,b; Rugg & Barrett, 1987). This negative wave peaks about 450 msec after the onset of the second member of a stimulus pair. Although it exhibits a slightly stronger right-hemisphere dominant amplitude distribution than the N400 related to semantic processing, it is usually considered to be the same component (for reviews see, for instance, Kutas & Van Petten, 1988; Pritchard, Shappell, & Brandt, 1991).

An N400 sensitive to phonological variables can be elicited not only by visually, but also by auditorily presented stimuli. Using a rhyme judgment task, Praamstra and Stegeman (1993) found that in a time window of 300 to 600 msec after the onset of the second member of a stimulus pair, brain potentials were more negative to unrelated than to rhyming pairs of words or nonwords. A similar effect, albeit restricted to words, was found in a lexical decision experiment.

Holcomb and Neville (1990) and O'Rourke and Holcomb (1992), also using the lexical decision task, found N400 effects for spoken nonwords compared to words. Interestingly, in O'Rourke and Holcomb's experiment, the negativity began earlier for stimuli that became nonwords approximately three segments after word onset than for stimuli that became nonwords later. This suggests that the time course of the processing of verbal stimuli can be reflected in the timing of ERP effects.

The present study is closely related to the studies by Praamstra and Stegeman and by O'Rourke and Holcomb. As in Praamstra and Stegeman's experiment, a primed lexical decision task was used. The primes were monosyllabic Dutch words, and the targets were monosyllabic words or nonwords that were either phonologically related or unrelated to the targets. Subjects performed lexical decisions on the targets, and reaction times, errors, and evoked potentials were recorded.

The experiments reported below differ from Praamstra and Stegeman's in the following ways. First, additional electrodes were placed to allow for a closer examination of the spatial distribution of the ERP effects. Second, instead of an immediate response task, a delayed response task was used in order to reduce the likelihood of artifacts due to response execution. Thus, the subjects did not react to the targets immediately, but only upon presentation of a response cue played 1200 msec after target onset. A shortcoming of this procedure is that the reaction times and error rates are not very informative, as 1200 msec after target onset most of the stimulus processing should be completed. To obtain valid behavioral data, the experiments were also carried out using an immediate response task requiring subjects to react to each target as soon as they could. Thus, two groups of subjects participated in each experiment, one performing the delayed, and the other the immediate response task. Event-related potentials were recorded only for the former group.

The third, and most important difference to Praamstra and Stegeman's study is that different types of prime-target relationships were tested. In the first experiment, related primes and targets rhymed [as in ***graaf-staaf*** (duke–stick)], and in the second experiment they alliterated, i.e., they shared the onset consonant or consonant cluster and the vowel [as in ***beeld-beest*** (statue-animal)]. Testing different types of materials seemed important for three reasons. First, it seemed desirable to test whether Praamstra and Stegeman's behavioral results could be replicated with alliterating prime-target pairs, because the behavioral results of available lexical decision experiments testing prime-target pairs with shared word-initial segments are inconsistent. Jakimik, Cole, and Rudnicky (1985) reported that word and nonword decisions for monosyllabic targets were facilitated by polysyllabic prime words corresponding in their first syllable to the targets in both sound and spelling (as is, for instance, the case in *napkin–nap*). By contrast, Radeau, Morais, and Dewier (1989) found interference from primes sharing initial segments with the targets, provided prime and target were both words or both nonwords.

Slowiaczek and Pisoni (1986) found no priming effect when monosyllabic prime words were combined with monosyllabic target words or nonwords with which they shared one, two, or three word-initial segments. Finally, Goldinger, Luce, Pisoni, and Marcario (1992) also failed to obtain phonological priming when targets were presented in the clear. However, when they were presented in noise and when 50% of the prime-target pairs were related, significant facilitation was obtained from primes that had the first segment in common with the targets. This effect disappeared when only 10% of the pairs were related.

The reasons for the inconsistency of these results are unclear. Most likely, the strength and direction of priming effects depend on a number of interacting factors, such as specific stimulus processing strategies induced in the experiments and the type of prime-target relationship. That the latter factor might be an important determinant of priming effects is suggested by the results of two studies using a *visual* lexical decision task. Colombo (1986) tested Italian speakers and found that reactions to low-frequency targets were slower after primes beginning with the same letters as the targets than after unrelated primes and faster after primes ending with the same letters. Lukatela and Turvey (1990), testing Serbo-Croatian speakers, found that primes differing from the targets only in the word-initial letter facilitated the reactions relative to unrelated primes, whereas primes differing from the targets in a medial or final letter inhibited the reactions. Given this evidence from visual lexical decision experiments, it appeared useful to vary the type of phonological relationship between primes and targets in an auditory lexical decision experiment. The results should contribute to our understanding of priming effects and, ultimately, of the processing of spoken words.

The second reason for testing different types of prime-target relationships was to determine how closely evoked potentials and behavioral data from different experimental conditions correspond to each other. Corresponding results for both types of variables would suggest that the same, or closely related processes are measured, whereas discrepancies would indicate that different processes are measured. Both patterns might lead to interesting conclusions concerning the nature of the processes reflected in the behavioral and ERP results.

The third reason for comparing priming effects for rhyming and alliterating stimulus pairs was to obtain further evidence for O'Rourke and Holcomb's (1992) suggestion that the time course of processing auditorily presented verbal stimuli might be reflected in the timing of certain ERP components. Relevant evidence can be obtained from both word and nonword trials. For words, differences in the event-related potentials to related and unrelated stimulus pairs might be expected in both experiments. However, as the segments shared by the words in related pairs appear word-finally in Experiment 1 and word-initially in Experiment 2, the ERP effect might appear later in Experiment 1 than in Experiment 2.

The nonword targets of both experiments included a phonotactically illegal consonant cluster, i.e., a consonant cluster that does not appear in any Dutch syllable. This cluster appeared word-initially in Experiment 1 and word-finally in Experiment 2. It is possible that the position of the illegal cluster affects the processing of the targets. When a nonword is presented that begins with an illegal cluster, lexical access is probably quickly terminated because the cluster provides sufficient evidence that the target is not a word. By contrast, lexical search for a nonword ending in an illegal cluster might be maintained longer because the beginning of the target does not reveal whether or not it is a word. Thus, the occurrence of ERP differences between unrelated and related word–nonword pairs might depend on whether the illegal cluster precedes or follows the (mis)matching part of the members of a pair. One might predict an effect for the nonwords of Experiment 2, in which the illegal cluster appears word-finally, but not for those of Experiment 1, in which it appears word-initially.

If we find that the timing of the effect for word-word pairs depends on the word-position of the shared segments in related pairs, and that the presence of the effect for word-nonword pairs hinges on the position of the illegal cluster, O'Rourke and Holcomb's (1992) suggestion would be supported that ERP components can be identified that are sensitive to the time course of processing auditorily presented verbal stimuli.

To summarize, one goal of the present study was to establish whether a phonological priming effect would be obtained for alliterating, as well as for rhyming prime-target pairs. This should contribute to our understanding of the determinants of priming effects and, ultimately, of the process of spoken word recognition. A second goal was to explore certain properties of evoked potentials registered during the processing of the prime-target pairs. Specifically, the aim was to obtain further evidence for an ERP component that is sensitive to phonological variables, and to test whether the temporal properties of this component reflect the time course of auditory word recognition. If this is the case, evoked potentials might become an important tool for future research on the processing of the phonological forms of words.

RESULTS AND DISCUSSION OF EXPERIMENT 1

Behavioral Measures

Immediate Responses

Error Rates. The error rate was significantly lower for rhyming than for unrelated prime-target pairs [3.12 vs. 5.52%; $F1(1,11) = 15.68$, $MSe = 0.70$; $p < 0.01$; $F2(1,39) = 5.28$; $MSe = 0.63$, $p < 0.05$]. The difference between rhyming and unrelated pairs was larger for word than nonword targets (see Table 1); however, the interaction of PRIME-TYPE and TARGET-TYPE was only significant by items, but not by subjects [$F1(1,11) = 1.31$, $MSe = 5.75$; $F2(1,39) = 4.09$, $MSe = 0.55$, $p < 0.05$].

Reaction Times. The mean lexical decision time was shorter by 29 msec for nonword than for word targets, but this difference was only significant by items [means: 893 vs. 922 msec; $F1(1,11) = 4.50$, $MSe = 2254$, $p < 0.10$; $F2(1,39) = 7.61$, $MSe = 4451$, $p < 0.01$]. The reaction times were significantly shorter for rhyming than for unrelated pairs [means: 886 vs. 930 msec; $F1(1,11) = 98.67$, $MSe = 233$, $p < 0.01$; $F2(1,39) = 29.39$, $MSe = 2610$, $p < 0.01$]. The interaction of TARGET-TYPE and PRIME-TYPE was likewise significant [$F1(1,11) = 37.42$, $MSe = 666$, $p < 0.01$; $F2(1,39) = 34.42$, $MSe = 2423$, $p < 0.01$]. As Table 1 shows, a substantial priming effect (of 89 msec) was obtained for word targets. Thus, reaction times, as error rates, show that the decisions on word targets were facilitated by rhyming relative to unrelated primes. By contrast, for nonwords, the reaction times for rhyming and unrelated stimuli were almost identical (894 vs. 892 msec).

In this experiment, phonotactically illegal clusters appeared in only one target position, namely in the target onset. All targets with phonotactically legal onsets were words. Therefore, subjects could have made both word and nonword decisions on the basis of the onset alone. However, for unrelated pairs, the reaction times were

Table 1. Mean Reaction Times (RT) in Milliseconds and Error Rates (E%) for Immediate Responses in Experiment 1

	Target-Type		
Prime-Type	*Word*	*Nonword*	*Mean*
Rhyme			
RT	878	894	886
E%	2.5	3.75	3.12
Unrelated			
RT	967	892	930
E%	6.88	4.17	5.52
Mean			
RT	922	893	908
E%	4.69	3.96	4.32

significantly slower for word than for nonword targets [$F1(1,11) = 23.11$, $MSe = 1460$, $p < 0.01$; $F2(1,39) = 32.73$, $MSe = 3437$, $p < 0.01$ in analyses of simple effects], and, as mentioned above, the phonological priming effect was confined to word decisions. This suggests that the subjects processed word and nonwords targets somewhat differently. They probably made nonword decisions as soon as they noted the illegality of the onset cluster, but processed the entire targets before making word decisions. Thus, they did not adopt a specific response strategy for the present materials, but used a more general strategy that could also have been applied if the position of the illegal cluster had been variable.

Delayed Responses

Error Rates. The error rate for delayed responses was 3.02%. As Table 2 shows, the errors were distributed fairly evenly across the experimental conditions. In the analyses of variance, none of the main effects nor their interaction reached significance.

Reaction Times. Latencies were slightly shorter after rhyming than after unrelated primes, but this difference was not significant [means: 500 vs. 510 msec; $F1(1,11) = 1.92$, $MSe = 698$; $F2(1,39) = 2.59$, $MSe = 1747$]. Thus, the priming effect obtained for immediate responses was not replicated for delayed responses. Apparently, priming affects an early stage of target processing, which is usually completed 1200 msec after target onset.

A puzzling finding is that delayed responses were significantly faster for nonwords than for words [means: 486 ms vs. 524 ms; $F1(1,11) = 6.23$, $MSe = 2711$, $p < 0.05$; $F2(1,39) = 29.94$, $MSe = 1875$, $p < 0.01$]. If the subjects had used the 1200-msec-delay between target onset and response signal to fully prepare their responses, word and nonword decisions should have been equally fast. The reaction time difference between words and nonwords indicates that the subjects postponed some part of the response preparation until the response signal appeared. What these postponed processes might be cannot be inferred from the present data.

Table 2. Mean Reaction Times (RT) in Milliseconds (Measured from the Onset of the Response Signal) and Error Rates (E%) for Delayed Responses in Experiment 1

	Target-Type		
Prime-Type	*Word*	*Nonword*	*Mean*
Rhyme			
RT	519	480	500
E%	2.29	3.54	2.92
Unrelated			
RT	528	492	510
E%	3.13	3.13	3.13
Mean			
RT	524	486	505
E%	2.71	3.33	3.02

ERP Measures

The ERP waveforms for word and nonword targets are presented in Figure 1a and b, respectively. The responses, in particular those to word targets, were characterized by a high-amplitude broad negative wave with frontocentral maximum. This wave immediately followed the exogenous N1/P2 complex and stood out very prominently, partly because of the low amplitude of the N1/P2 complex, which was probably due to the short interstimulus interval between prime and target. At posterior electrode sites the waveforms were dominated by a prominent positive wave peaking around 800 msec, which represents the P300 or Late Positive Component (LPC).

For words, but not for nonwords, there was a difference between responses to targets preceded by rhyming or unrelated primes. In a time window from 450 to 700 msec, the responses to unrelated pairs were more negative than those to rhyming pairs at all electrode sites except for the mastoid sites. In the following sections, the results of the analyses of the mean amplitudes in selected time windows are reported.

Epoch 0–250 msec. A significant main effect of HEMISPHERE was obtained [$F(1,11) = 15.10$, $MSe = 1.23$, $p < 0.01$], which was due to higher amplitudes (negative sign) over the left than the right hemisphere.

Epoch 250–450 msec. Analysis of the mean amplitudes yielded a significant main effect of ELECTRODE [$F(1,11) = 11.22$, $MSe = 7.75$, $p < 0.01$]. This effect was related to the distribution of the anterior negative wave, whose rising slope appeared in this analysis window.

Epoch 450–700 msec. Significant main effects of PRIME-TYPE [$F(1,11) = 9.02$, $MSe = 42.63$, $p < 0.05$] and TARGET-TYPE [$F(1,11) = 17.00$, $MSe = 60.30$, $p < 0.01$] and a significant interaction of these variables were obtained [$F(1,11) = 9.96$, $MSe = 18.66$, $p < 0.01$]. Analysis of simple effects showed that the effect of PRIME-TYPE was significant for word targets [$F(1,11) = 18.10$, $MSe = 30.65$, $p < 0.01$] but not for nonword targets [$F(1,11) < 1$, $MSe = 30.65$]. The interaction of TARGET-TYPE and HEMISPHERE was also significant [$F(1,11) = 5.64$, $MSe = 3.75$, $p < 0.05$]. For word targets, the mean amplitudes were higher (negative sign) over the right than over the left hemisphere, whereas the reverse was true for nonword targets. Finally, a main effect of ELECTRODE [$F(1,11) = 17.30$, $MSe = 22.98$, $p < 0.01$] was related to the overlap of this analysis window with the LPC. The characteristic LPC distribution caused an anteroposterior amplitude

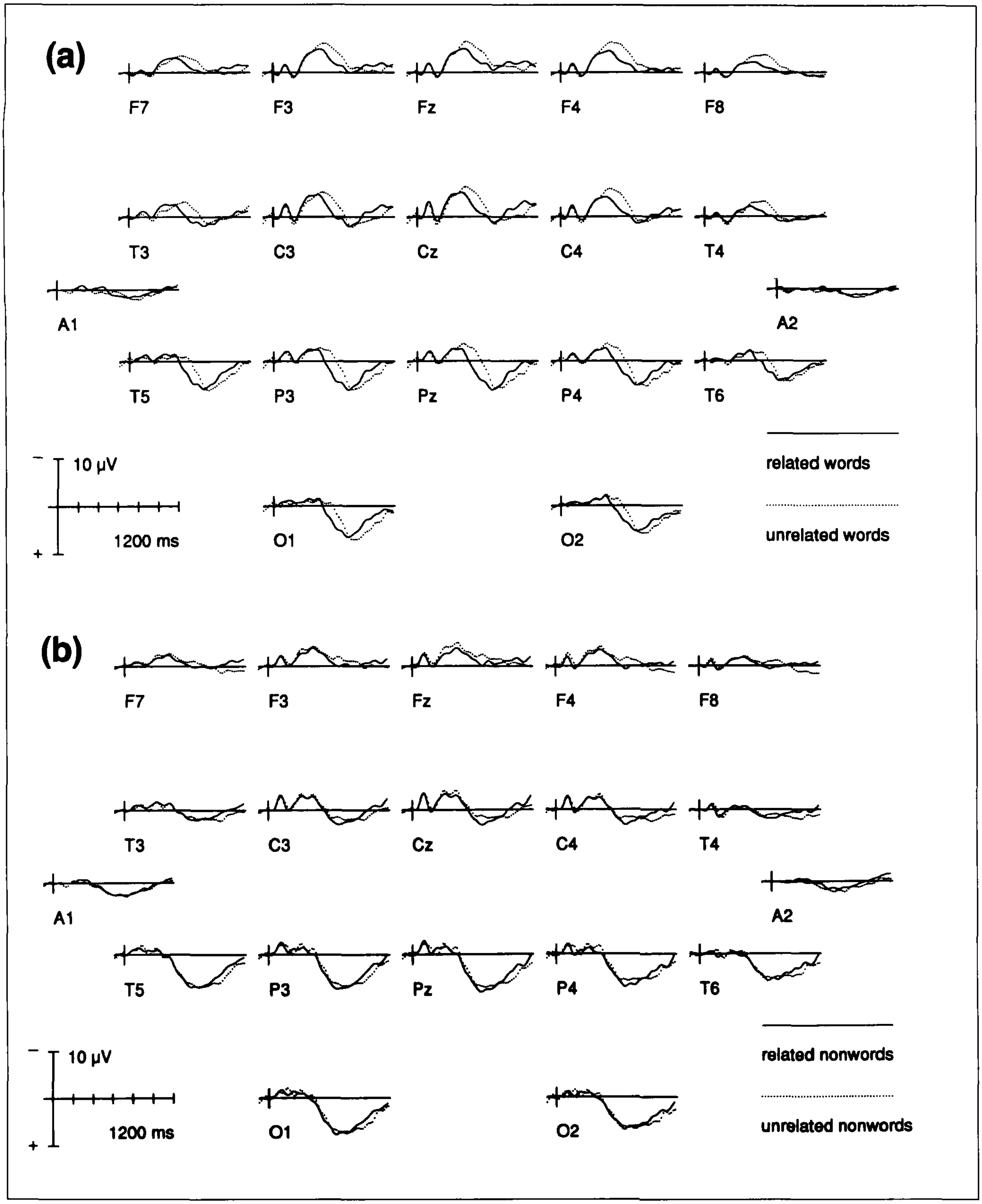

Figure 1. (**a**) Grand average ERPs for related and unrelated word targets in Experiment 1. (**b**) Grand average ERPs for related and unrelated nonword targets in Experiment 1.

gradient with highest positive amplitudes at parietal and occipital sites.

Epoch 700–1000 msec. The responses to nonwords had significantly higher (positive) amplitudes than the responses to words [$F(1,11) = 6.22$, $MSe = 106.25$, $p < 0.05$]. As in the preceding latency window, the LPC distribution resulted in a significant main effect of ELECTRODE [$F(1,11) = 38.93$, $MSe = 16.61$, $p < 0.01$].

LPC Latency and Amplitude. LPC amplitude measured at Pz was higher for nonword than for word targets [$F(1,11) = 6.31$, $MSe = 9.20$, $p < 0.05$; see Table 3]. LPC latency was longer by about 60 msec for word targets combined with unrelated primes than for the remaining three types of prime-target combinations. However, in the analyses of variance, none of the main effects nor their interaction was significant.

Discussion

As in Praamstra and Stegeman's (1993) lexical decision experiment, ERP differences between rhyming and unrelated word pairs were found in the 450- to 700-ms epoch, providing evidence for a phonological effect on a late negative component. Due to the larger number of channels used in the present than in the previous study closer examination of the topography of this ERP effect was possible, revealing a symmetrical distribution without pronounced differences between anterior and posterior electrode sites. Subtraction of the brain responses to rhyming words from those to unrelated words showed highest amplitudes at central and parietal electrode sites. Because of the widespread distribution of the effect it is unlikely that an LPC latency difference between responses to rhyming and unrelated word pairs importantly contributed to the ERP effect, which overlapped with the LPC only at posterior electrode sites.

Rhyming and unrelated word pairs differed in LPC latency by 62 msec. This difference was in the same order of magnitude as the priming effect for reaction times in the immediate response task (see Tables 2 and 3). Given that LPC latency is related to stimulus evaluation time (Magliero, Bashore, Coles, & Donchin, 1984), this similarity in the patterns of results suggests that subjects in the delayed and immediate response tasks processed the stimuli in similar ways.

The distribution of the negative enhancement that distinguished the ERP waves to unrelated and rhyming word pairs is compatible with the proposal that this effect reflects a modulation of the N400 (Praamstra & Stegeman, 1993). The latency at which the waveforms separated, which was between 400 and 500 msec after target onset, could be considered late, however, compared to the onset found in studies of semantic effects on the auditory N400 (Holcomb & Neville, 1990; McCallum, Farmer, & Pocock, 1984). The relatively late onset of the N400 in the present experiment can probably be explained by the fact that related and unrelated word pairs differed in whether or not they ended in the same segments. Hence, the effect could arise only after most of the target had been processed. By contrast, a semantic effect on the N400 might begin earlier after word onset, in particular in cases where, given the context, one particular word is strongly expected.

The negative enhancement for unrelated relative to rhyming pairs was found only for word but not for nonword targets. Recall that the priming effects obtained in the analyses of reaction times and error rates for immediate responses were likewise confined to word targets. The absence of priming effects for nonword targets can be explained by assuming that the processing of nonword targets was terminated before enough time had elapsed for priming effects to develop. The confinement of both the behavioral and ERP effects to words suggests that both effects reflect on the same, or closely related processes, and that they both arise during or after lexical access to the targets rather than during the perception of the acoustic input.

Table 3. Mean LPC Latencies (lat) in Milliseconds and Amplitudes (amp) in Microvolts in Experiment 1

	Target-Type		
Prime-Type	*Word*	*Nonword*	*Mean*
Rhyme			
lat	794	796	795
amp	7.9	10.0	8.95
Unrelated			
lat	856	800	828
amp	7.4	9.7	8.55
Mean			
lat	825	798	812
amp	7.65	9.85	8.75

RESULTS OF EXPERIMENT 2

The second experiment differed from the first in the stimulus materials. In Experiment 1, the related prime-target pairs rhymed, and in Experiment 2, they alliterated. The nonwords of Experiment 1 began with an illegal cluster, whereas those of Experiment 2 ended with such a cluster.

Behavioral Measures

Immediate Responses

Error Rates. The mean error rate was significantly higher for word than for nonword targets [13.33 vs. 4.27%; $F1(1,11) = 69.21$, $MSe = 2.28$, $p < 0.01$; $F2(1,39) = 16.05$, $MSe = 2.95$, $p < 0.01$; see Table 4).

Table 4. Mean Reaction Times (RT) in Milliseconds and Error Rates (E%) for Immediate Responses in Experiment 2

	Target-Type		
Prime-Type	*Word*	*Nonword*	*Mean*
Alliteration			
RT	980	941	960
E%	12.50	3.54	8.02
Unrelated			
RT	967	952	960
E%	14.17	5.00	9.59
Mean			
RT	974	946	960
E%	13.33	4.27	8.80

Table 5. Mean Reaction Times (RT) in Milliseconds (Measured from the Onset of the Response Signal) and Error Rates (E%) for Delayed Responses in Experiment 2

	Target-Type		
Prime-Type	*Word*	*Nonword*	*Mean*
Alliteration			
RT	507	466	486
E%	7.08	2.92	5.00
Unrelated			
RT	519	477	498
E%	7.92	4.17	6.04
Mean			
RT	513	471	492
E%	7.50	3.54	5.52

Furthermore, the error rate was higher for unrelated than for alliterating pairs (9.59 vs. 8.02%), but this difference was not significant [$F1(1,11) = 1.84$; $MSe = 2.55$; $F2(1,39) < 1$; $MSe = 2.53$].[1]

Reaction Times. The main effect of PRIME-TYPE was not significant; in fact, the mean reaction times for alliterating and unrelated pairs were identical (960 msec). As Table 4 reveals, reactions to word targets were slightly slower after alliterating than after unrelated primes, whereas the reverse was true for reactions to nonword targets. The interaction of PRIME-TYPE and TARGET-TYPE was significant by subjects, but not by items [$F1(1,11) = 6.24$, $MSe = 275$, $p < 0.05$; $F2(1,39) = 1.15$, $MSe = 4915$]. Analyses of simple effects showed that neither the inhibitory effect of alliterating primes for words nor the facilitatory effect for nonwords was statistically significant [$F1(1,11) = 4.59$, $MSe = 221$, $p < 0.10$; $F2(1,39) < 1$, $MSe = 6923$ for words; $F1(1,11) = 3.28$, $MSe = 726$, $p < 0.10$; $F2(1,39) < 1$, $MSe = 2420$ for nonwords targets].

As in Experiment 1, lexical decisions were significantly faster for nonwords than for words [means: 946 vs. 974 msec; $F1(1,11) = 7.05$, $MSe = 1268$, $p < 0.05$; $F2(1,39) = 5.58$, $MSe = 5374$, $p < 0.05$]. This suggests that subjects did not base word decisions solely on phonotactic criteria (in which case one might expect word and nonword decisions to be equally fast), but that they checked whether the phonotactically legal strings corresponded to existing entries in the mental lexicon.

Delayed Responses

Error Rates. The error rate for delayed responses was 5.52%. As for immediate responses, the error rate was significantly higher for words than for nonwords [7.50 vs. 3.54%; $F1(1,11) = 7.89$, $MSe = 3.81$, $p < 0.05$; $F2(1,39) = 4.32$, $MSe = 2.09$, $p < 0.05$; see Table 5].

Reaction Times. In the analyses of the lexical decision latencies, a significant main effect of TARGET-TYPE was obtained with shorter latencies for nonwords than for words [means: 471 vs. 513 msec; $F1(1,11) = 16.43$, $MSe = 1279$, $p < 0.01$; $F2(1,39) = 32.16$, $MSe = 2185$, $p < 0.01$]. As can be seen from Table 5, latencies were slightly faster after alliterating than after unrelated primes for both words and nonwords, but the effect of PRIME-TYPE was not significant [$F1(1,11) = 2.54$, $MSe = 635$; $F2(1,39) = 2.18$, $MSe = 2441$].

ERP Measures

The ERP waveforms for word and nonword targets are presented in Figure 2a and b, respectively. As in Experiment 1, a broad negative wave of high amplitude was observed at central and frontal sites, extending from approximately 250 to 700 msec after target onset. The waveforms were more negative for unrelated than for alliterating prime-target pairs. For word targets, the effect began, at parietal and occipital electrode sites, as early as the N1 peak latency, and it was limited to the rising slope and the peak of the negative wave. For nonword targets the difference between alliterating and unrelated pairs began slightly later and extended over the entire broad negative wave. Following the anterior negativity, there was the posteriorly distributed LPC. Finally, there was, in particular at central and left frontocentral sites, a negative shift in the interval between 800 and 1200 msec. Most likely, this represents anticipatory activity (related to the Contingent Negative Variation), preceding the auditory signal for the delayed response. The waveforms were analyzed using the same epochs as in Experiment 1.

Epoch 0–250 msec. The mean amplitude was significantly higher (negative sign) over the left than the right hemisphere [$F(1,11) = 8.39$, $MSe = 1.81$, $p < 0.05$]. However, at F3 and F4 this asymmetry was reversed yielding a significant interaction of HEMISPHERE and ELECTRODE [$F(1,11) = 5.07$, $MSe = .31$, $p < 0.05$]. A

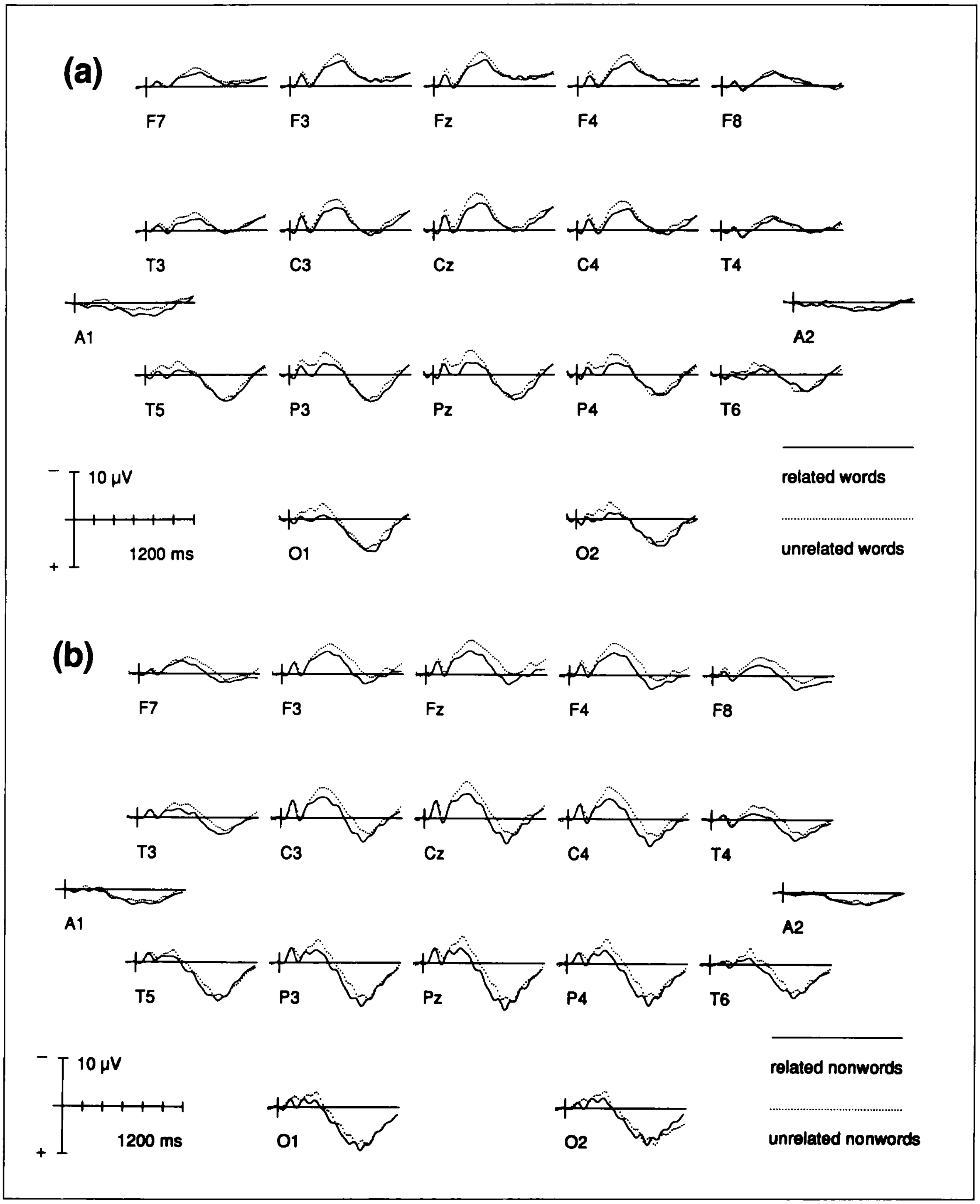

Figure 2. (**a**) Grand average ERPs for related and unrelated word targets in Experiment 2. (**b**) Grand average ERPs for related and unrelated nonword targets in Experiment 2.

significant main effect of ELECTRODE [$F(1,11) = 6.71$, $MSe = 2.46, p < 0.05$] was due to highest mean amplitudes, for this window, at parietal sites.

Epoch 250–450 msec. The mean amplitude was significantly higher for unrelated than for alliterating pairs [$F(1,11) = 11.26$, $MSe = 22.06, p < 0.01$]. A significant main effect of ELECTRODE [$F(1,11) = 15.54, MSe = 9.20$, $p < 0.01$] was related to an amplitude distribution with frontocentral maximum.

Epoch 450–700 msec. This time window comprised part of the rising slope of the LPC. Therefore, a steep anteroposterior amplitude gradient was observed yielding a significant main effect of ELECTRODE [$F(1,11)$ 24.13, $MSe = 21.84, p < 0.01$].

Epoch 700–1000 msec. A significant main effect of TARGET-TYPE [$F(1,11) = 7.19$, $MSe = 68.88, p < 0.05$] was due to different LPC amplitudes for words and nonwords. The characteristic distribution of the LPC, with parietal maximum, was responsible for a main effect of ELECTRODE [$F(1,11) = 16.60, MSe = 27.54, p < 0.01$].

LPC Latency and Amplitude. For LPC latencies a significant interaction of PRIME-TYPE and TARGET-TYPE was obtained [$F(1,11) = 5.68$, $MSe = 3608.97, p < 0.05$; see Table 6]. For word targets, latencies were longer when alliterating than when unrelated primes were presented. The reverse was true for nonword targets. LPC amplitude was significantly higher for nonword than for word targets [$F(1,11) = 20.24$, $MSe = 11.96, p < 0.01$].

Thus, as in Experiment 1, an ERP difference between related and unrelated prime-target pairs was obtained. However, this effect occurred considerably earlier than in Experiment 1, and instead of being confined to word targets, it was found for nonword as well as for word targets. A comparison of the scalp distributions of these effects to the effect found for words in Experiment 1 yielded no significant main effect of EXPERIMENT nor significant interactions of EXPERIMENT with HEMISPHERE or ELECTRODE.

Table 6. Mean LPC Latencies (lat) in Milliseconds and Amplitudes (amp) in Microvolts in Experiment 2

	Target-Type		
Prime-Type	*Word*	*Nonword*	*Mean*
Alliteration			
lat	863	807	835
amp	6.8	11.5	9.15
Unrelated			
lat	826	853	840
amp	6.0	10.2	8.10
Mean			
lat	845	830	837
amp	6.40	10.85	8.63

GENERAL DISCUSSION

Behavioral Data

In the analyses of the behavioral data a reliable priming effect was obtained for word targets when prime and target rhymed, but not when they alliterated. Thus, the effect of related primes depended on the word positions of the shared segments.

As mentioned in the Introduction, similar results have been obtained by Colombo (1986) and by Lukatela and Turvey (1990) using a visual lexical decision task. In these studies, reactions were slower after primes sharing initial letters with the targets than after unrelated primes and faster after primes sharing non-initial letters with the targets. To account for their findings, Colombo and Lukatela and Turvey assume that form-related primes generally facilitate target processing, but that inhibition can also arise under certain circumstances. In the mental lexicon, words are taken to be represented as units at one level and as sets of letters and segments at other levels. Each word unit is connected to its constituent letters and segments. Form-related words are connected to the same letters and/or segments. When a prime is seen, its letters are activated and in their turn they activate all words they are part of. The set of activated words includes the prime and, when prime and target are graphemically related, the target as well. Because of the preactivation of some of its letters and of its word unit by the prime, the target can usually be perceived more rapidly after a related than after an unrelated prime. However, when a target is activated very strongly by a prime, it is inhibited by neighboring word units and therefore becomes *less* accessible than a target preceded by an unrelated prime. (The assumption that strongly activated word units receive inhibition is introduced in order to keep the units' activation levels within bounds; see Grossberg, 1978).

Primes sharing word-initial segments with the targets probably activate them so strongly that their activation level exceeds the inhibition threshold. By contrast, primes sharing noninitial letters with the targets activate them only to a level below that threshold. Thus, lexical decision latencies are longer after initial-letter primes than after unrelated primes and shorter after other types of related primes. The reason why initial-letter primes are more powerful than other related primes could be that initial letters themselves are activated more strongly than other letters by the input and therefore pass more activation to superordinate units. The allocation of the inhibitory effect at the lexical level is supported by Colombo's (1986) findings that the effect was obtained only for word, but not for nonword targets, and that it depended on target frequency [for a discussion of the localization of facilitatory and inhibitory effects see also Slowiaczek & Hamburger (1992) and Slowiaczek, Nusbaum, & Pisoni (1987)].

The present data can be explained along similar lines. Both rhyming and alliterating primes activated some of the target segments and the target word units. As rhyming primes activated the targets' word units to a level below the inhibition threshold, facilitation was observed. By contrast, alliterating primes activated the targets to a level above that threshold, and the inhibitory effect arising at the word level cancelled the facilitatory effect arising at the sublexical level. Hence, no priming effect was observed.

Alternatively, the priming effect in Experiment 1 might be due to postlexical processes. Subjects in lexical decision experiments often engage in processes that are not task-relevant (e.g., Forster, 1981; de Groot, 1985; Lorch, Balota, & Stamm, 1986; Seidenberg, Waters, Sanders, & Langer, 1984). In primed lexical decision experiments with high proportions of related prime-target pairs, they tend to check whether prime and target are related, and the outcome of this congruency test can affect response latency (e.g., Jakimik, Cole, & Rudnicky, 1985; Radeau, Morais, & Dewier, 1989; Slowiaczek & Pisoni, 1986). The subjects of Experiment 1 probably checked whether prime and target rhymed. For related word pairs, the outcome of this congruency test and the lexical decision were both positive, but for unrelated word pairs, the congruency test and the lexical decision process yielded conflicting results. The reaction time difference between rhyming and unrelated word pairs might be due to the extra processing time needed to overcome the resulting response conflict. A possible explanation for the absence of a reversed effect for nonword targets is that the lexical decision process for nonwords was much faster than the congruency test, and that the overt response was initiated before the congruency test was completed. Given the short reaction times for nonword targets, this assumption is not implausible. Another possibility is that the congruency check was, for whatever reason, not carried out when the target included an illegal cluster.

To explain the absence of a priming effect in Experiment 2, it must be assumed that subjects in that experiment either did not evaluate the prime-target relationship or that this process was completed too late to affect the reaction times. Word game studies (e.g., Treiman, 1983; 1986) and speech error analyses (e.g., Shattuck-Hufnagel, 1983) have shown that rhymes are more salient and coherent units than syllable-initial consonant-vowel groups. Thus, subjects might be more likely to perform congruency tests when rhyming than when alliterating pairs are presented. However, if the reaction times of Experiment 1, but not those of Experiment 2 had been affected by the outcome of congruency tests, mean latencies for words preceded by unrelated primes should have been longer in the former, than in the latter experiment. The mean latencies were, however, identical (967 msec).

Thus, the behavioral results are amenable to at least two accounts. One is that the related primes in both experiments activated the target word units, but did so to varying degrees so that inhibition arose in one, but not in the other experiment. The other account is that subjects performed postlexical congruency tests in Experiment 1, but not in Experiment 2. The latter account does not appear particularly plausible to us, but it cannot be ruled out with certainty.

ERP Data

The priming effect in the behavioral data of Experiment 1 was accompanied by a corresponding ERP effect. In the time window of 450 to 700 msec, the mean amplitudes at most electrode sites were more negative for unrelated than for rhyming stimulus pairs. This replicates the main result of Praamstra and Stegeman's (1993) lexical decision experiment. The replication of this effect in the present study, in which a delayed instead of an immediate response task was used and spatial sampling was improved by using a larger number of electrodes, renders an interpretation of the effect as caused by an LPC latency shift implausible. Praamstra and Stegeman's experiments showed that the ERP effect most likely did not arise during the processing of the physical signal. Thus, taken together the results of the two studies show that an ERP component can be identified that is sensitive to phonological variables.

In Experiment 2, there was evidence for phonological priming only in the ERP, but not in the behavioral data. Moreover, the ERP effect differed from the effect obtained in Experiment 1 in that it arose earlier and was obtained for words and nonwords, whereas it was confined to words in the first experiment. Hence, the question must be considered whether the same or different components were measured in the two experiments. We will consider these possibilities in turn.

On the "same-component hypothesis," the difference in the timing of the effect can be attributed to the fact that in Experiment 1 prime and target of related pairs ended with the same segments, whereas in Experiment 2 they began with the same segments. Thus, the timing of the ERP effect can be taken to reflect the fact that the shared segments appeared later in the former than in the latter experiment. As pointed out in the Introduction, a difference in the timing of the effect was expected on the basis of O'Rourke and Holcomb's (1992) findings.

The finding that the effect was obtained only for word targets in Experiment 1, but for word and nonword targets in Experiment 2 can be due to the fact that the illegal clusters appeared in different positions in the nonwords of the two experiments. Lexical search for the nonwords of Experiment 1, which began with illegal clusters, was probably terminated before a priming effect could develop. By contrast, lexical search for the nonwords of Experiment 2, which ended in illegal clusters, was likely to continue long enough for the prime to take an effect. This assumption is supported by the finding that reactions to nonwords were faster in Experiment 1 than in Experiment 2 (893 vs. 946 msec).

The same-component hypothesis implies that the same process was affected in all conditions where a priming effect was obtained. What could the affected process be? One possibility is that it is the activation of shared vs. different phonological segments by prime and target. As discussed above, the priming effect for word targets in Experiment 1 could be due to preactivation of some of the targets' segments by the related primes. Preactivation also occurred for word and nonword targets in Experiment 2, but here its effect was masked by the effect of lexical competition. It did not take place for nonword targets in Experiment 1 because lexical access was terminated before the effect could develop. Thus, target segments were preactivated in exactly those three conditions where significant ERP effects were observed.

Alternatively, the process reflected in the ERP effects could be a postlexical congruency test. The subjects probably tested on each trial whether prime and target were related in form, and the outcome of this test was reflected in the ERP waveform. This proposal is similar to Rugg and Barrett's (1987; Barrett & Rugg, 1990) interpretation of the late negative wave they found when subjects performed rhyme judgements for visually presented words and pictures (see also Brown & Hagoort, 1993; Rugg, 1990; Stuss, Picton, & Cerri, 1988).

A postlexical account has already been suggested in the above discussion of the reaction times. However, such an account cannot coherently explain all results of the present study. Specifically, in Experiment 2, a priming effect for word and nonword targets was seen in the ERP, but not in the behavioral data. Hence, in order to explain the ERP data, it must be postulated that subjects performed congruency tests, whereas an account of the reaction time data implies that they did not perform such tests. One might argue that reaction times and ERP data reflect on different types of processes, and that the accounts for the two data sets need not be compatible; yet, a coherent account of both data sets would be more parsimonious and interesting.

To summarize, the same-component hypothesis implies that the same ERP component was measured in both experiments. We discussed two types of processes to which this component might be related. One is the repeated activation of the same vs. different segments by primes and targets, and the other is a congruency test performed for certain prime-target pairs. Of these two alternatives, the former seems to offer a more coherent and parsimonious account of the data.

On the "different-components hypothesis," the differences between the ERP results of Experiments 1 and 2 indicate that modulations of different ERP components were measured. As the difference between related and unrelated stimulus pairs arose earlier in Experiment 2 than in Experiment 1, and as in Experiment 2 it pertained to both words and nonword targets, the effect obtained in that experiment could reflect the physical, rather than the phonological match or mismatch between primes and targets. Thus, it could be a mismatch negativity (MMN) or an N2.

However, the MMN differs in topography from the component recorded in the present study. The MMN typically has a more frontal distribution and a slight right-hemisphere preponderance, and it shows a polarity reversal at posterolateral electrode sites, which can be attributed to its generation near the supratemporal plane (Giard, Perrin, & Pernier, 1990; Paavilainen, Alho, Reinikainen, Sams, & Näätänen, 1991). In addition, the MMN is elicited by infrequent stimuli that are physically deviant from the frequent ones and are not consciously processed (Näätänen, 1990). In the present experiments, related and unrelated prime-target pairs occurred equally often, and the subjects consciously processed the targets and, most likely, the primes as well. Thus, an account of the extra negativity in unrelated pairs as MMN seems implausible.

In contrast to the MMN, the N2 requires conscious processing of the eliciting stimuli. This condition was fulfilled in the present experiments. However, physical changes of verbal stimuli only elicit an N2 if they are task-relevant (Deacon, Breton, Ritter, & Vaughan, 1991), which was not the case in the present experiments. In addition, like the MMN, the N2 requires a low probability of mismatching stimuli (Näätänen & Picton, 1986). Finally, if the negative enhancement were a modulation of the N2, one would expect differential effects on the subsequent positivity (Näätänen & Picton, 1986), which were, however, not observed.

Thus, though alternative explanations cannot be ruled out with certainty, an account of the ERP results of both experiments as modulations of the same component is most parsimonious. The differences in the ERP and behavioral results between the experiments can be explained as due to differences in the stimulus materials. On this view, the results indicate that the measured component reflects certain aspects of the phonological processing of auditorily presented stimuli. A specific hypothesis advanced above is that it might be sensitive to the repeated activation of the same vs. different phonological segments by prime and target. The different timing of the component in Experiments 1 and 2 can be taken to be due to the fact that the shared segments appeared in different word positions in the two experiments.

A final point to discuss is whether, assuming that the ERP effects in Experiments 1 and 2 are manifestations of the same component, this component is the N400. The effects obtained in Rugg's (1984a,b) and Praamstra and Stegeman's (1993) investigations of rhyming stimulus pairs could naturally be classified as N400 effects, although they occurred quite late. By contrast, the ERP effects in our Experiment 2 occurred unexpectedly early. However, short onset latencies for an auditory N400 (between 50 ms and 200 ms) have also been found by Holcomb and Neville (1991) for sentence-final semantically anomalous words. As in our Experiment 2, N400 onsets were found earlier over occipital and parietal than over more frontal electrode sites. According to Holcomb and Neville the early onset of the N400 in their experiment was due to the fact that evoked potentials were measured during the processing of sentences spoken at a normal rate with normal intonation. Probably phonetic and intonational cues that are not present when word pairs are presented auditorily or when words or sentences are presented visually facilitated the processing of the target words such that they were rapidly recognized as semantically inappropriate. In Experiment 2 of the present study, the segments that were identical in related prime-target pairs and different in unrelated pairs occurred at the word onset. Hence, the match or mismatch of prime and target could probably likewise rapidly be detected, leading to an early ERP effect.

As the early timing of the negative enhancement in Experiment 2 seems not incompatible with an interpretation as a modulation of the N400 and as, furthermore, the scalp distributions of the negativities in Experiments 1 and 2 are not untypical for this component, it does not seem inappropriate to refer to the effects as N400 effects. However, one might object to this classification of the effects because the experimental variable eliciting them was phonological rather than semantic, and because the proposed interpretation does not agree with the predominant view of the N400 as reflecting postlexical integrative processes (e.g., Brown & Hagoort, 1993; Holcomb, 1993; Rugg, 1990; Stuss, Picton, & Cerri, 1988).

We believe that the negativity found in our experiments is similar enough to the "classical" N400 to be provisionally placed in the same category. However, as explained in the Introduction, the goal of the present study was not to test whether the N400 was sensitive to phonological variables. Instead, the aim was to determine whether it was at all possible to identify a component (which might or might not be the N400) that would be sensitive to phonological information, and, if so, whether this component would reflect the time course of the processing of spoken words. Both questions can be answered affirmatively. This supports the view that event-related potentials might become a useful tool in the study of spoken word processing.

METHOD

Subjects

The experiments were carried out with 24 subjects. All subjects participated in both experiments. Twelve subjects (eight men and four women) performed the immediate response task, and 12 (six men and six women) the delayed response task. The subjects' mean age was 27 years (range 21 to 39 years). All subjects were right-handed native speakers of Dutch. They were undergraduate students of the University of Nijmegen. They were paid for their participation in the experiments.

Stimuli

The stimuli of each experiment consisted of 40 monosyllabic prime words and 160 monosyllabic targets. Each prime was combined with four targets, namely a phonologically related and an unrelated word, and a phonologically related and an unrelated nonword. In the first experiment, the phonologically related targets rhymed, and in the second experiment they alliterated with the primes. The nonwords of Experiment 1 began with a phonotactically illegal consonant cluster, and those of Experiment 2 ended with such a cluster (see Van der Hulst, 1984 for a discussion of the phonotactic rules of Dutch). The phonotactically illegal clusters were chosen such that they clearly marked the stimuli as nonwords, but could still be pronounced by a trained speaker.

The related and unrelated targets of each experiment were matched as closely as possible in frequency. Estimates of word frequency were based on the CELEX corpus (Burnage, 1991). In Experiment 1, the mean log frequencies of rhyming and unrelated targets were 1.29 and 1.44 per million occurrences, respectively; the mean log frequency of the primes was 1.55 per million occurrences. In Experiment 2, the mean log frequencies of alliterating and unrelated targets were 1.02 and 1.68, respectively, and the mean log frequency of the primes was 1.69 per million occurrences.

The targets of different conditions were matched in duration. In Experiment 1, the mean durations of rhyming and unrelated word targets were 529 and 527 msec, respectively. The mean durations of rhyming and unrelated nonword targets were 569 and 547 msec, respectively. The mean duration of the primes was 488 msec. In Experiment 2, the mean durations of alliterating and unrelated word targets were 493 and 499 msec, respectively, and the mean durations of rhyming and unrelated nonword targets were 483 and 481 msec, respectively. Finally, the mean duration of the primes was 494 msec.

The entire set of 160 prime-target pairs was divided into four blocks of 40 pairs each. Within each block, each of the 40 primes occurred once. Ten primes each were combined with related and unrelated words and with related and unrelated nonwords.

Across the four blocks, each prime was combined once with a target of each type. The order of the pairs within blocks was random and different for each block. Thus, each subject heard each prime four times, followed by different targets. Half the targets were words and half were nonwords, and half the prime-target pairs were related and half were unrelated. For presentation to the subjects, the four blocks were combined to form two test blocks of 80 prime-target pairs each. Twelve subjects started with the one and 12 with the other test block.

The stimuli were spoken by a male speaker. They were digitally recorded in a sound attenuated room. Word onsets and offsets were determined using a speech waveform editor. The digitized stimuli were stored on the hard disc of an IBM PS/2 computer, D/A converted with 12 bit resolution, amplified, filtered, and presented binaurally via Sony MDR-V3 headphones.

Procedure

Subjects were tested individually in a quiet room. The EEG and computer equipment was located in a neighboring room, from which subjects could be observed by the experimenter through a one-way screen. In the written instructions, the subjects were informed about the nature of the lexical decision task. They were told that the nonwords included consonant clusters that did not normally occur in Dutch, and that some of the prime-target pairs would rhyme (Experiment 1) or alliterate (Experiment 2). Subjects performing the immediate response task were asked to react to each target as quickly as possible. Subjects performing the delayed response task were told to prepare for the reaction and to press one of two response buttons as soon as they heard the response signal.

Following electrode application, subjects were seated in a comfortable chair and were instructed to move as little as possible and to fixate a point in front of them. In each hand, subjects held one push button, which was mounted on a cylindrical hand grip and could be pressed with the thumb. The assignment of the "yes" and "no" response buttons to the two hands was rotated across subjects.

Twelve subjects, six in the immediate and six in the delayed response condition, began with Experiment 1, the others with Experiment 2. Each experiment began with the practice block, which was immediately followed by the first test block. After a short pause, the second test block was administered. Between experiments, there was a pause of ten to fifteen minutes.

On each trial, one prime-target pair was presented. The target began 750 msec after prime onset. In the delayed response condition, a response signal, which was a 1-kHz sine-tone with a duration of 50 msec, was played 1200 msec after target onset. The intertrial interval was 3500 msec in the immediate, and 4700 msec in the delayed response condition.

EEG Recording

The EEG was recorded with tin electrodes (Electro-Cap International) at three midline sites, Fz, Cz, Pz, and 16 lateral sites, F7 and F8, F3 and F4, T3 and T4, C3 and C4, T5 and T6, P3 and P4, O1 and O2, and A1 and A2. All electrodes were referenced to the nose tip. Horizontal EOG was recorded from electrodes placed at left and right outer canthus; vertical EOG was recorded by means of electrodes supra- and infraorbital to the right eye. Electrode impedance was kept below 3 kΩ. Electrical activity was amplified by a Nihon-Kohden MME-3132K bio-electric amplifier with a time constant of 10 sec and 35 Hz low pass filter setting. The EEG was digitized beginning 100 msec prior to target onset for a duration of 1300 msec, using a sample frequency of 250 points per second.

Data Analyses

To analyze the ERP data, mean amplitudes were computed per subject, electrode, and condition (i.e., for each of the four types of prime-target pairs), using only correct trials without conspicuous artifacts. After inspection of the grand average waveforms, the following time windows were selected: 0–250 msec (encompassing the exogenous P1, N1, and P2 components), 250–450 msec (corresponding to the negative enhancement in Experiment II), 450–700 msec (corresponding to the negative enhancement in Experiment I), and 700–1000 msec [P300 or Late Positive Component (LPC)]. In addition, the peak latency and amplitude of the LPC were determined at Pz. Separate analyses of variance were carried out for each window, with PRIME-TYPE (rhyming vs. unrelated in Experiment 1, and alliterating vs. unrelated in Experiment 2), TARGET-TYPE (word vs. nonword), ELECTRODE (7 sites: F7/8, F3/4, T3/4, C3/4, T5/6, P3/4, O1/O2), and HEMISPHERE (left/right) as crossed within-subjects variables. Geisser–Greenhouse conservative F-tests were used. An additional analysis for the three midline sites Fz, Cz, and Pz provided no new information and is not reported.

To eliminate spurious interactions involving the variable ELECTRODE, additional analyses were carried out on normalized data, as suggested by McCarthy and Wood (1985). Interactions involving ELECTRODE are reported only when they were significant in the analyses on the normalized data, as well as in the main analyses. The F-values of the latter analyses are reported.

The scalp distributions of the ERP effects obtained in Experiments 1 and 2 were compared by entering the amplitude difference between the responses to related and unrelated targets in the relevant time windows (450–700 msec in Experiment 1 and 250–450 msec in Experiment 2) into analyses of variance with EXPERIMENT, HEMISPHERE, and ELECTRODE as within-subject variables. The effects for word and nonword targets in Experiment 2 were compared separately to the effect for word targets of Experiment 1.

Reaction times for correct responses and error rates were analyzed using analyses of variance with PRIME-TYPE and TARGET-TYPE as crossed variables. Analyses were performed with subjects (*F1*) and items (*F2*) as random variables. Separate analyses were carried out for each experiment and for immediate and delayed responses.

APPENDIX

Stimuli Experiment 1

Prime Words	Rhyming Words	Rhyming Nonwords	Nonrhyming Words	Nonrhyming Nonwords
schat	krat	zrat	kruis	zruis
vloed	spoed	tloed	spijs	tlijs
bruid	kruid	tnuit	kraal	tnaal
geld	speld	zleld	sport	zlort
buik	pruik	bnuik	prop	bnop
stier	klier	vnier	kloof	vnoof
plaag	kraag	zmaag	kroon	zmoon
nood	brood	fmoot	broer	fmoer
graaf	staaf	kjaaf	steeg	ljeeg
draf	staf	bnaf	stoom	bnoom
troef	proef	vnoef	pret	vnet
druif	kluif	pwuif	klip	pwip
spek	plek	fmek	plaat	fmaat
klik	prik	bjik	praat	bjaat
luik	kruik	znuik	kras	znas
dijk	lijk	bnijk	leer	bneer
taak	spaak	pwaak	spier	pwier
bouw	trouw	zlouw	trek	zlek
blok	klok	tmok	kluit	tmuit
rook	spook	tlook	spuug	tluug
peuk	breuk	zjeuk	brief	zjief
stuk	pluk	bnuk	plas	bnas
paal	staal	tlaal	ster	tler
vuur	stuur	zmuur	stam	zmam
doel	stoel	zroel	stem	zrem
peil	dweil	fneil	dwaas	fnaas
sloop	knoop	tsoop	knal	tsal
faam	kraam	zmaam	kroeg	zmoeg
kram	gram	vnam	griep	vniep
kiem	priem	dliem	prijs	dlijs
zoom	droom	kmoom	draad	kmaat
speen	steen	vneen	stof	vnof
brein	trein	djein	troep	djoep
groep	stoep	vmoep	steun	vmeun
slof	plof	tnof	pluim	tnuim
teef	dreef	tseef	drup	tsup
zweep	greep	dleep	grot	dlot
plak	slak	tmak	sleur	tmeur
pluis	gruis	kmuis	gril	kmil

Stimuli Experiment 1

Prime Words	Alliterating Words	Alliterating Nonwords	Nonalliterating Words	Nonalliterating Nonwords
kost	korf	kofp	verf	vefp
hark	halt	hanf	milt	minf
beeld	beest	beeln	mast	maln
pels	perk	pewp	bark	bawp
vacht	valk	varl	wolk	worl
kust	kurk	kukp	merk	mekp
harp	halm	harw	film	firw
pols	pomp	posf	ramp	rasf
veld	vent	vepk	pont	popk
lamp	larf	lawk	durf	duwk
hemd	heks	hemn	reeks	reemn
gesp	gerst	gepf	borst	bopf
belt	berk	bemk	jurk	jumk
punt	pulp	purw	welp	werw
vink	vilt	vinp	teelt	teenp
vonk	volt	vofp	held	hefp
rang	rasp	rakp	wesp	wekp
bint	bink	binf	wenk	wenf
gift	gips	gitp	mops	motp
honk	homp	hokf	kamp	kakf
mars	mark	marl	zerk	zerl
mest	merg	mefk	zorg	zofk
kern	kelk	kepk	balk	bapk
golf	gong	gofp	ding	difp
borg	bocht	bojp	jacht	jajp
rots	romp	rofk	kemp	kefk
munt	muts	musf	toets	toesf
kink	kift	kifp	hoofd	hoofp
rund	rust	rutk	post	potk
telg	test	terl	puist	puirl
wand	walm	wamk	helm	hemk
werk	wens	wefk	kans	kafk
naam	naald	naakf	schuld	schukf
dans	darm	datf	vorm	votf
tulp	turf	tusf	kerf	kesf
wild	winst	wikp	dienst	diekp
worm	wond	wonf	band	banf
komst	kolf	kofk	schelf	schefk
kind	kist	kinp	lust	lunp
park	pand	pamk	hond	homk

Acknowledgments

The authors thank Dorothee Chwilla, Lyn Frazier, Dick Stegeman, Pienie Zwitserlood, and two anonymous reviewers for comments on the manuscript, Jan Moleman and Leo Haeghens for technical support, Sabine Kooijman for running the experiments, and Karin Roeleveld for preparing the figures.

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Note

1. The error rate for immediate responses was much higher in Experiment 2 than in Experiment 1 (8.80 vs. 4.32%). This difference stems from the difference in error rates for word targets, which were 13.33% for Experiment 2 and 4.69% for Experiment 1. Inspection of the error distribution across items showed that the high error rate in Experiment 2 was not due to a few particularly error-prone items. The words of the two experiments were closely matched in frequency. As they were spoken by the same speaker in a single session, the stimulus quality should be the same. Both experiments were performed with the same subjects in a single session. At present no explanation of the difference in error rates can be offered.

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