Research Article

Detecting Silent Pauses in Speech

A New Tool for Measuring On-Line Lexical and Semantic Processing

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ABSTRACT—***In this study, we introduce pause detection (PD) as a new tool for studying the on-line integration of lexical and semantic information during speech comprehension. When listeners were asked to detect 200-ms pauses inserted into the last words of spoken sentences, their detection latencies were influenced by the lexical-semantic information provided by the sentences. Listeners took longer to detect a pause when it was inserted within a word that had multiple potential endings, rather than a unique ending, in the context of the sentence. An event-related potential (ERP) variant of the PD procedure revealed brain correlates of pauses as early as 101 to 125 ms following pause onset and patterns of lexical-semantic integration that mirrored those obtained with PD within 160 ms of pause onset. Thus, both the behavioral and the electrophysiological responses to pauses suggest that lexical and semantic processes are highly interactive and that their integration occurs rapidly during speech comprehension.***

The speed with which listeners detect silent pauses in speech has been shown to provide an on-line measure of lexical activation (Mattys & Clark, 2002). For example, a pause following a speech fragment with few or no possible lexical completions (e.g., "kes[p] . . . ," with "[p]" indicating a pause) is detected faster than one following a fragment with several possible completions (e.g., "des[p] . . ."). A similar effect is found for pause detection (PD) following early-unique words (i.e., words that deviate from all other lexical candidates before their offset, e.g., "vulture[p] . . .") compared with late-unique words or words that could be embedded at the beginning of longer words (e.g., "counter[p] . . ."). PD is also sensitive to the changes in lexical activation caused by exposure to novel words. For instance, Gaskell and Dumay (2003) showed that PD in early-unique words such as "cathe[p]dral" becomes slower if participants have been repeatedly exposed to a novel competitor such as "cathedruke" prior to the PD task. This lexicalization effect suggests that PD is sensitive not only to the structure of a stabilized lexicon, but also to the changes undergone by a developing lexicon.

Because speech processing is constrained by the transient nature of the acoustic input (Mattys, 1997), a complete account of spoken-word recognition requires that lexical activity be investigated in the context of the unfolding speech signal. In particular, lexical activity in connected speech is thought to depend not only on lexical constraints (Luce & Pisoni, 1998; Marslen-Wilson, 1987; Norris, 1994), but also on the interaction between these constraints and the semantic information provided by sentential context (Grosjean, 1980; McAllister, 1988; Tyler & Wessels, 1983; Zwitserlood, 1989). In theory, the point in a word at which it is uniquely identified can be pushed earlier in time if the preceding sentential context increases the likelihood for this word to occur. The question is, does the modulation of lexical activity by semantic information take place on-line (cf. Van Petten, Coulson, Rubin, Plante, & Parks, 1999)?

In the study reported here, we investigated lexical-semantic integration using PD. Spoken sentences, some of which contained a pause, were played to listeners asked to detect the pauses as fast as they could. In the critical trials, the pause was inserted into early-unique versus late-unique words appearing toward the end of semantically constraining versus neutral sentences. In an attempt to capture the modulation of lexical activity by sentential semantics as accurately as possible, we selected the test words and their carrier sentences in a pilot word-completion experiment. We describe the selection criteria in the next section.

Participants in all the experiments were native-English students from the University of Bristol, United Kingdom. They received course credit or a small honorarium for their participation. None reported a history of hearing difficulties.

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WORD AND SENTENCE SELECTION

Method

Participants

Thirty students participated in this pilot experiment.

Materials

Seventy-six trisyllabic words with primary stress on the second syllable were selected. Note that some of these words might be classified as quadrisyllabic, depending on whether the nucleus of the third syllable is realized as a diphthong or not. When considered in isolation, half the words reached lexical uniqueness before the offset of the second syllable (early-unique), whereas the other half reached uniqueness after offset of that syllable (late-unique). Uniqueness points were estimated using the Celex database (Baayen, Piepenbrock, & Gulikers, 1995). Each word was embedded at the end of two sentences: One provided a semantically constraining context for the word, whereas the other was neutral (see Table 1 for examples). The two sentences were matched on their syntactic structure, as well as their duration. Attempts were made to keep the latter part of the two sentences, which included the test word, identical. Furthermore, to minimize possible acoustic differences in the common fraction of the two sentences, we used the waveform of the test word and of some material preceding it for both sentences. The splicing point preceded the pause by an average of 580 ms. The splicing procedure ensured that differences in processing between the constraining and neutral conditions could not be due to acoustic idiosyncrasies. Because of the multiple constraints on word and context selection, this procedure could not be applied to the lexical-uniqueness variable. For this particular study, however, this limitation was not critical because the effect of context was examined separately for early-unique and late-unique words. Direct comparisons between early- and late-unique sets were played down.

TABLE 1

Examples of Sentences Ending With Early- Versus Late-Unique Words in Semantically Constraining Versus Neutral Contexts

Condition	Example
Early-unique	
Constraining	The stars on the American flag are symbo[p]lic.
Neutral	The letters on the window sill are symbo[p]lic.
Late-unique	
Constraining	The childbirth was a painful deli[p]very.
Neutral	The tribe had a gleeful deli[p]very.

Note. In the pilot experiment, the sentences were presented without the last syllable. [p] indicates the location of the pause in the pause-detection experiment and the pause-present condition of the event-related potential experiment. The average duration of the first two syllables of the test words was 308 ms in the early-unique set and 297 ms in the late-unique set, $t(48) = 0.67$, $p = .51$.

Procedure and Design

The sentences were recorded in a sound-attenuated booth by a male native speaker of southern British English. The speaker was instructed to say the sentences in a conversational and connected manner (i.e., all speech segments were naturally coarticulated). After the splicing procedure was applied, the final syllable of each test word was digitally removed. The truncated sentences were then played, one at a time, to the participants, who were instructed to complete the final word of each sentence by typing it on a computer keyboard. So that participants would not be exposed to both the constraining and the neutral versions of a given test word, we presented each participant with the constraining version for half the words and the neutral version for the other half. This assignment was counterbalanced across two subgroups of 15 participants.

Results

The cloze probability (Bloom & Fischler, 1980) of the intended word in a particular sentence was estimated as the probability of guessing the word correctly. A lexical-deviation index was then estimated as 1 minus the cloze probability. On the basis of the lexical-deviation scores obtained for the 76 pairs of sentences, 50 were kept. Twenty-five ended with a truncated word that could easily be identified whether the context was constraining or neutral (the early-unique set). The other 25 ended with a truncated word that could be uniquely identified only in the constraining context (the late-unique set). The 25 early-unique and 25 late-unique words from which the truncated disyllables originated were matched, pair-wise, on their lexical frequency (513 vs. 536 per million, from Celex), $t(24) = -0.12$, n.s. (see Table 2 for a complete stimulus list). Average diphone probability and lexical neighborhood density (estimated as the number of words departing from the disyllable by a one-phoneme substitution, deletion, or addition in any position; Luce & Pisoni, 1998) for the two sets of disyllables (i.e., the truncated early-unique and late-unique trisyllables) revealed contrasts consistent with the uniqueness data, namely, greater diphone probability and neighborhood density for the late-unique than the early-unique stimuli, $t(24) = 2.79$, $p = .01$, and $t(24) = 5.48$, $p < .001$, respectively. By definition, late-unique words are more likely than early-unique words to share materials with other words—particularly their early fragments. Indeed, diphone probabilities were found to differ between the first syllables of the early- and late-unique disyllables, $t(24) = 2.92$, $p < .01$, but not between the second syllables, $t(24) = 1.07$, n.s.

The 50 test stimuli were selected from the larger set such that uniqueness and sentential context showed a clear interaction, $F_1(1, 29) = 51.57$, $p < .001$; $F_2(1, 48) = 118.17$, $p < .001$. Specifically, early-unique words had equally low lexical-deviation scores in the constraining and neutral contexts ($M = .02$, $SD = .04$, and $M = .04$, $SD = .06$, respectively), $F_1(1, 29) = 1.83$, $p = .19$; $F_2(1, 24) = 2.62$, $p = .12$. Thus, early-unique

TABLE 2
Test Words

Early-unique words: approval, cathedral, disaster, enormous, experience, forbidden, foundation, graffiti, historian, horizon, mysterious, November, outstanding, peculiar, perspective, pajamas, potato, remember, starvation, symbolic, taxation, tomatoes, tremendous, tribunal, volcano
Late-unique words: commission, complacent, conception, concerning, concussion, confession, December, defective, delivery, department, detective, determined, director, discussion, diversion, elections, exception, excluded, expected, intention, permission, professor, recession, recipient, redundant

words could be identified before the pause regardless of the sentential context. In contrast, the identification of the late-unique words was contingent on the sentential context, $F_1(1, 29) = 41.68, p < .001$; $F_2(1, 24) = 139.47, p < .001$. Although the neutral context yielded multiple cloze completions ($M = .60, SD = .24$), as expected from the Celex estimates (e.g., the first two syllables of "delivery" are shared with "delirium," "delinquent," "deliverance," etc.), the constraining sentential context allowed the late-unique words to be uniquely identified ($M = .07, SD = .10$). Thus, the word-completion data provide an off-line estimate of the lexical activity at the end of the second syllable, that is, where the pause would be inserted in the PD experiment.

PAUSE DETECTION: BEHAVIORAL DATA

If PD latencies reflect on-line lexical-semantic integration, a pattern of results similar to that observed in the pilot experiment should emerge when participants are instructed to detect pauses inserted in these words in the same locations.

Method

Participants and Stimuli
Thirty-eight participants were recruited for this experiment. The test sentences were those of the pilot experiment, except that they were played in full, with the final syllable of the test words delayed by 200 ms of silence. In addition, 99 filler sentences contained a pause in earlier locations. In these sentences, the pause was inserted in various positions within bisyllabic, trisyllabic, and quadrisyllabic words. Finally, 74 sentences did not contain a pause.

Procedure
The 273 sentences were randomized, with at least 40 trials intervening between the constraining and neutral sentences for each test word. On each trial, participants were instructed to press a key as soon as they heard the pause, and another key if they thought the sentence did not contain a pause. They were not encouraged to pay attention to either the phonological or the semantic content of the sentences.

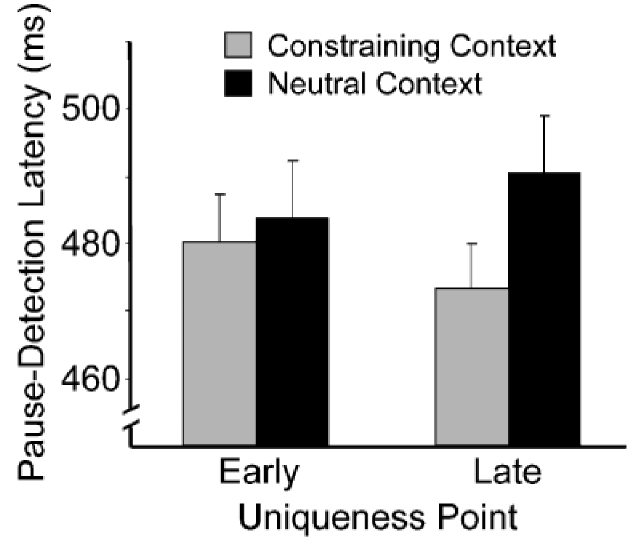

Fig. 1. Pause-detection latencies, measured from the onset of the pause, as a function of word uniqueness and sentential context.

Results and Discussion

PD latencies were measured from the onset of the pauses. Incorrect responses (2.4% of the trials) were discarded. In addition, correct PD responses whose latency was shorter than 100 ms or longer than 2 standard deviations from the participant's mean were discarded. Altogether, the discarded responses amounted to 6.2% of the test trials. As can be seen in Figure 1, PD latencies showed a pattern similar to that of the lexical-deviation scores in the pilot experiment. In particular, uniqueness and context interacted, $F_1(1, 37) = 7.74, p < .01$, and $F_2(1, 24) = 5.54, p < .03$; context did not have an effect in the early-unique condition, $F_1(1, 37)$ and $F_2(1, 24) < 1$, but had a significant effect in the late-unique condition, $F_1(1, 37) = 8.70, p = .005$, and $F_2(1, 24) = 6.57, p < .02$. Thus, a pause was detected faster if the speech fragment preceding the pause had only one or few possible lexical completions in the context of the sentence than if it had many. These results suggest that PD latency is a reliable index not only of the lexical activity generated by words themselves (Gaskell & Dumay, 2003; Mattys & Clark, 2002), but also of the modulation of such activity by the sentential context in which the words appear.

ELECTROPHYSIOLOGICAL DATA

In an attempt to specify the earliness of lexical-semantic integration as well as the physiological correlates of pause perception, we measured event-related potentials (ERPs) elicited by the test sentences with and without pauses. This investigation was motivated by evidence that ERPs are sensitive to both temporal disruptions in speech (Besson, Faita, Czternasty, &

Kutas, 1997) and cloze probability (Kutas & Hillyard, 1980, 1984; Van Petten et al., 1999). Specifically, Besson et al. found that the insertion of a silent pause in spoken sentences elicits an emitted potential consisting of a negative component peaking around 200 ms after the onset of the pause, followed by a positive component around 100 to 200 ms later. The elicited potential, particularly its later component, is more pronounced when the pause precedes a predictable word (e.g., the final word of a familiar proverb) than when it precedes a less predictable word (e.g., the final word of a neutral sentence). Similarly, words presented in uninterrupted sentences elicit a larger negative potential (N400) if their semantic relationship to the preceding context is incongruent than if it is congruent (Kutas & Hillyard, 1980, 1984; Van Petten, 1995). These studies converge in showing that sentential disruptions, whether temporal or semantic, tend to produce transient negativity, the magnitude of which is a function of the degree of lexical-semantic expectation at the time the violation of expectancy is encountered. Thus, ERPs might be informative in specifying the time course of PD and, hence, that of lexical-semantic integration.

Method

Participants, Materials, and Design

Twenty participants took part in this experiment. The sentences were those of the PD experiment, except that pause-absent versions of the test sentences were also included to constitute a baseline for the pause-present sentences. Thus, in all, there were 373 sentences. These were randomized such that there were at least 40 trials intervening between any of the four sentences in which a given test word appeared (i.e., pause-present constraining, pause-present neutral, pause-absent constraining, pause-absent neutral).

Apparatus and Procedure

Electroencephalographic (EEG) data were recorded with a time constant of 10 s and a low-pass filter set to 40 Hz. The data were acquired in 30 channels at 200 Hz with a precision of 32 bits/μV. The following electrode sites, derived from the American Electroencephalographic Society 10% equidistant system, were selected: F7, F8, F3, F4, FC5, FC6, FC3, FC4, T7, T8, C3, C4, CP5, CP6, CP3, CP4, P7, P8, P3, P4, PO3, PO4, O1, O2, Fpz, Fz, FCz, Cz, Pz, Oz. Vertical and horizontal electro-oculograms (EOGs) were recorded from electrodes located above and below the right eye and from the outer canthi, respectively. All recordings employed Ag/AgCl electrodes. EEG recordings were referred to linked mastoids. In addition, EOG artifacts were removed using regression calculations applied separately to blinks and vertical and horizontal eye movements (Conway, Pleydell-Pearce, & Whitecross, 2001; Gratton, Coles, & Donchin, 1983).

Following EOG correction, computer algorithms examined the EEG associated with the final word of each sentence and rejected trials on which there were excessive artifacts associated with the electromyogram data, slow-potential shifts, or large transients. This led to the rejection of 4.1% of the pause-present test-sentence trials and 3.7% of the pause-absent test-sentence trials. For some analyses that employed analysis of variance (ANOVA), interactions between conditions and topography were normalized according to established guidelines (McCarthy & Wood, 1985).[1]

In order to measure electrophysiological responses to the stimuli independently of the attentional and motoric components of PD, we asked the participants to pay attention only to what they heard and to rate each sentence's overall plausibility on a continuous scale from 0 (low) to 5 (high). The rating was prompted 1 s after the end of each sentence.

Results and Discussion

We first analyzed the plausibility scores to verify the validity of the sentential-context variable. As expected, the scores reflected the semantic contrast between constraining and neutral sentences, with the semantically constraining sentences judged more plausible than the neutral ones, $F(1, 19) = 257.98$, $p < .001$. However, context did not interact with uniqueness, $F(1, 19) = 1.78$, $p > .10$ (early-unique: $M = 4.26$, $SD = 0.39$ vs. $M = 1.71$, $SD = 0.86$; late-unique: $M = 4.08$, $SD = 0.32$ vs. $M = 1.44$, $SD = 0.82$), which confirms that the interaction observed in the PD task did not simply mirror an imbalance in the stimuli but, rather, was the genuine result of the modulation of lexical activity by semantic information.

All probabilities associated with the ANOVAs of the physiological data were epsilon corrected (where $df > 1$). Interactions between electrode and other factors were tested both with and without McCarthy and Wood (1985) scaling (henceforth, MWS). As illustrated for electrode FCz in Figure 2, the ERP data, averaged across all test conditions, showed that pauses elicited a large potential that resembled an N1-P2 complex (Besson et al., 1997; Kutas & Hillyard, 1989). N1 peak amplitude was defined as the largest negative value in the period from 101 to 200 ms following pause onset, and was calculated separately within participants and within conditions. Mean N1 peak latency was around 150 to 160 ms. P2 was similarly defined as the peak value within 201 to 300 ms following pause onset, and had a peak latency of 260 to 270 ms. The N1 and P2 components displayed maximal amplitude over fronto-central regions. A Pause (present vs. absent) × Electrode (30 sites) ANOVA was applied to sequential 25-ms epochs following pause onset. Main effects of pause presence versus absence were visible as early as 101 to 125 ms following pause onset (see Table 3). Post hoc analysis of significant interactions (see Table 4) indicated that the earliest topographic effects of pauses (with MWS) occurred in centro-parietal regions (Epoch 7), and by Epoch 8, significance spread to fronto-central electrodes. In the absence of

[1]Supporting material concerning the ERP technical and procedural details, as well as additional analyses, can be found on the Web at http://137.222.61.246/Pause_Detection/.

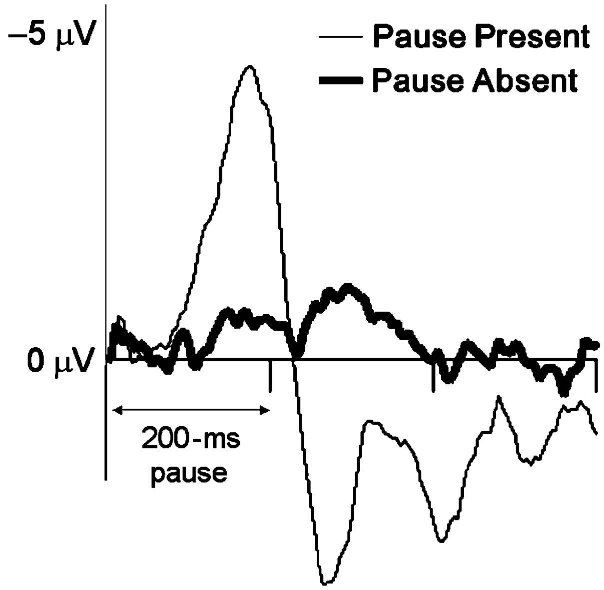

Fig. 2. Averaged event-related potentials for the FCz electrode, relative to a 200-ms prepause baseline, for the pause-present condition (time-locked to the onset of the pause) and the pause-absent condition (time-locked to the temporal location corresponding to the onset of the pause in the pause-present condition).

MWS, the interaction was significant in Epochs 6, 7, and 8, and earliest effects included frontal and centro-parietal regions.

Thus, a physiological response to the pauses was visible after only slightly more than the duration range of articulatory pauses (Hieke, Kowal, & O'Connell, 1983; Levin, Silverman, & Ford, 1967). Epochs 10, 11, and 12, which spanned the P2 component, also exhibited significant main effects of pauses and Pause × Electrode interactions (both with and without MWS). In all cases, pause presence was associated with greater positivity than pause absence, particularly over fronto-central regions.

In pause-present trials (Fig. 3a), pauses produced more negativity in the vicinity of N1 in the constraining sentences than in the neutral sentences, particularly in the late-unique condition. An Electrode (30 sites) × Uniqueness (early-unique vs. late-unique) × Sentential Context (constraining vs. neutral) ANOVA was applied to N1 peak amplitude. This revealed a significant three-way interaction, $F(29, 551) = 3.28$, $p < .05$ (MWS not applied, because N1 peak amplitude is not a stationary measure). Furthermore, the interaction between uniqueness and context was significant for the following electrodes: C3, F3, F7, FC3, FC5, FCz, Fz, O1, and Fpz, which all involve left-hemisphere or midline electrodes. In line with the behavioral results, significant effects of context were found in the late-unique condition but not in the early-unique condition at C3, F3, FCz, Fz, and Fpz (all $ps < .05$ in the late-unique condition). Late-unique items showed a lower N1 peak amplitude in the neutral than in the constraining sentences.

In an additional analysis, N1 amplitude was defined as the mean voltage over 101 through 200 ms following pause onset. The three-way interaction was significant both with MWS, $F(29, 551) = 2.91$, $p < .05$, and without MWS, $F(29, 551) = 2.86$, $p < .05$. Post hoc tests, with and without MWS, showed significant differences between the constraining and neutral contexts for late-unique trials at electrode Fpz.[2] In order to meet potential concerns about the stability of N1 peak amplitude latency, we

TABLE 3
Main Effects of Pause Presence Versus Absence on Electrical Potential, Collapsed Across Uniqueness and Context

Epoch	*MSE*	*F*(1, 19)	*p*
4 (76–100 ms)	22.50	<1	n.s.
5 (101–125 ms)	14.25	11.44	<.01
6 (126–150 ms)	16.55	24.55	<.001
7 (151–175 ms)	19.56	47.27	<.0001
8 (176–200 ms)	15.22	27.91	<.001
9 (201–225 ms)	12.37	<1	n.s.
10 (226–250 ms)	11.16	10.12	<.01
11 (251–275 ms)	30.60	16.37	<.01
12 (276–300 ms)	61.30	7.76	<.05

TABLE 4
Interactions Between Pause Presence/Absence and Electrode Location in the Analysis of Electric Potential Collapsed Across Uniqueness and Context

Epoch	*MSE*	*F*(29, 551)	*p*
4 (76–100 ms)	0.146	<1	n.s.
5 (101–125 ms)	0.045	2.33	n.s.
6 (126–150 ms)	0.036	2.17	n.s.
7 (151–175 ms)	0.030	4.42	<.01
8 (176–200 ms)	0.022	5.20	<.01
9 (201–225 ms)	0.021	1.49	n.s.
10 (226–250 ms)	0.027	1.00	n.s.
11 (251–275 ms)	0.028	4.00	<.05
12 (276–300 ms)	0.027	3.16	<.05

Note. All data were subjected to McCarthy and Wood (1985) scaling.

[2]To ensure that the patterns of results could not have been due to repeating the context sentences in the pause-absent and pause-present conditions, we reran the critical ANOVAs with repetition (first vs. second occurrence) as a control variable. The critical patterns of results were unchanged. In particular, although the analysis of N1 peak amplitude showed a significant three-way interaction of electrode, uniqueness, and context, $F(29, 551) = 2.52$, $p < .05$ (Huyhn-Feldt corrected), the four-way interaction, which included repetition, was not significant, $F(29, 551) = 1.29$. Neither was the interaction of uniqueness, context, and repetition, $F(1, 19) = 2.65$, $p > .12$, or any comparison involving the repetition factor. However, there was a main effect of repetition on N1 peak amplitude latency, $F(1, 19) = 7.83$, $p < .05$, with a slightly earlier peak for the second than the first presentation (151 ms vs. 157 ms), suggesting somewhat faster processing on the second than the first occurrence. A similar four-way ANOVA performed on the 101- through 200-ms postpause window replicated the critical three-way interaction, $F(19, 551) = 2.95$, $p < .05$, and did not reveal any interaction with the repetition variable, $F(19, 551) = 1.02$ for the four-way interaction and $F(1, 19) = 2.21$, $p > .15$, for the interaction of uniqueness, context, and repetition. Moreover, these patterns were not altered when MWS was not applied. Thus, none of these analyses suggest that the critical interaction between context and uniqueness can be attributed to repetition artifacts.

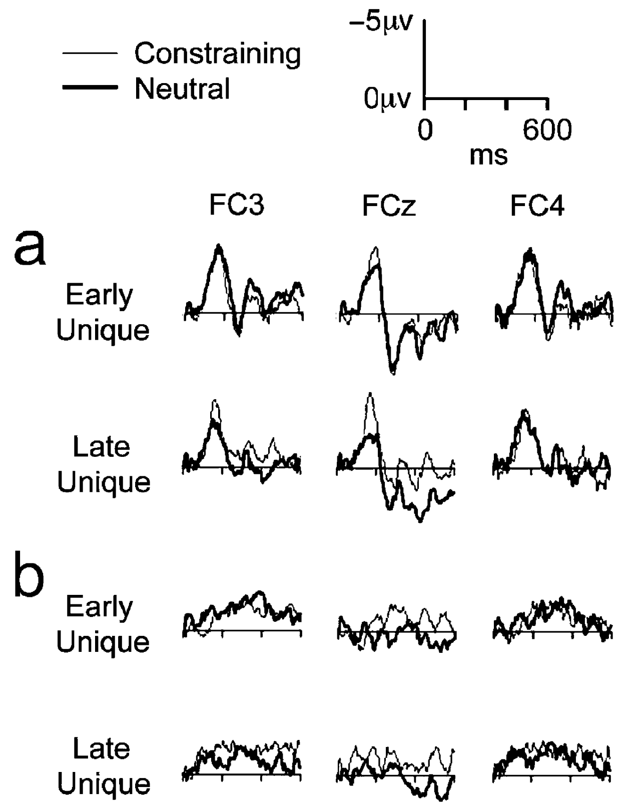

Fig. 3. Averaged event-related potentials for the FC3, FCz, and FC4 electrodes, broken down by word uniqueness and sentential context. Recording for the pause-present condition (a) was time-locked to the onset of the pause and measured relative to a 200-ms prepause baseline. Recording for the pause-absent condition (b) was time-locked to the temporal location corresponding to the onset of the pause in the pause-present condition and measured relative to a baseline averaged over the 200 ms preceding that location.

applied an Electrode × Uniqueness × Context ANOVA to this dependent variable. The critical three-way interaction was nonsignificant. Analyses run on later portions of the ERPs (201–400 ms, 401–600 ms, 601–800 ms), with MWS correction applied, did not reveal a three-way interaction either.

The interaction between uniqueness and context in the N1 peak amplitude analysis is consistent with two interpretations. On the one hand, it may indicate a less dramatic violation of lexical expectancy when the identity of the final word is ambiguous (i.e., has multiple completions) than when it can be established from the context. On the other hand, it can be interpreted as resulting from more resources being devoted to lexical processing in the neutral context of the late-unique condition and, consequently, fewer resources being left available for registering the rhythmic disruption (e.g., Raney, 1993). In either case, however, the pattern of results provides strong evidence for an early modulatory role of sentential context on lexical activity.

It might be objected that this pattern could have arisen even without the pauses, and that pauses do not have a unique contribution as probes into lexical activation. To test this hypothesis, we performed analyses on the pause-absent trials and constructed condition averages from the point where pauses would have been inserted. In a variety of analyses, including an analysis of peak negativity within the 101- through 200-ms period (Fig. 3b), none of the three-way or two-way (Uniqueness × Sentential Context) interactions were found to be significant (all Fs < 1.30). Thus, the critical interaction between uniqueness and context in the pause-present condition can be confidently attributed to the introduction of pauses into lexically critical portions of the speech stream.

GENERAL DISCUSSION

These results provide evidence that lexical and semantic processes are highly interactive and that their integration occurs rapidly during speech comprehension. In particular, the PD latencies indicate that the modulation of lexical processing by a prior sentential context takes place on-line, even when only partial lexical information is available. The electrophysiological data, and critically the difference in results between the pause-present and pause-absent conditions, not only highlight the cerebral correlates of the behavioral results, but also indicate that lexical-semantic integration can be seen as early as 160 ms after pause onset. This finding is consistent with results by O'Rourke and Holcomb (2002) showing latency differences in the N400 produced by isolated early-unique and late-unique disyllables shortly after their uniqueness point. It is also in line with results of Van Petten et al. (1999) showing differential N400 responses to contextually appropriate and inappropriate words 200 ms prior to the words' recognition point—determined by gating in isolation. Thus, our behavioral and electrophysiological data lend support to both early-integration positions (e.g., Friederici, Steinhauer, & Frisch, 1999; Van Petten et al., 1999) and sequential, left-to-right approaches to lexical activation (e.g., Gaskell & Marslen-Wilson, 1997; Marslen-Wilson, 1987; Marslen-Wilson & Zwitserlood, 1989; Zwitserlood, 1989).

Our findings also have bearing on the more general debate between modular and interactionist views of lexical-contextual integration (Simpson, 1994). The modular stance posits that lexical activation is an autonomous process, with all the meanings of a word initially accessed, even if the context is inconsistent (e.g., Onifer & Swinney, 1981). In contrast, interactionists propose that constraining effects of contextual information operate early on (e.g., Tabossi, 1988; Van Petten & Kutas, 1987). Although our results clearly support the interactionist view, they do not necessarily imply that the contextually inconsistent lexical candidates were not momentarily activated prior to the point at which the context-by-uniqueness interaction was observed, or weakly activated at that point. The possibility that inconsistent lexical candidates were activated to some extent, however, does not weaken the claim that semantic and lexical constraints interact well before a word's end.

On the basis of the evidence presented here, we propose that PD's sensitivity to lexical activity is due to both the processing resources required by pause detection and the violation of lexical expectancy that temporal disruptions occasion. According to this view, if lexical activity has stabilized to a single candidate at the time a pause is encountered (as happened in the present experiment with early-unique words and late-unique words in a semantically constraining context), resources can be diverted from linguistic to sensory processing, such as pause detection. This results in faster PD latencies and heightened consequences of rhythmic disruption (as reflected in N1 amplitude). In contrast, if lexical competition is still ongoing when a pause is encountered (as happened in the present experiment with late-unique words in a semantically neutral context), fewer processing resources are available to detect the pause, so PD latency is longer and the response to rhythmic violations (N1 amplitude) is reduced. Future research will need to determine whether these effects are specific to silent pauses or can be extended to other temporally disrupting events, such as tones or noise.

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