An Event-Related Potential (ERP) Analysis of Semantic Congruity and Repetition Effects in Sentences

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Abstract

■ In two experiments, event-related brain potentials (ERPs) and cued-recall performance measures were used to examine the consequences of semantic congruity and repetition on the processing of words in sentences. A set of sentences, half of which ended with words that rendered them semantically incongruous, was repeated either once (e.g., Experiment 1) or twice (e.g., Experiment 2). After each block of sentences, subjects were given all of the sentences and asked to recall the missing final words.

Repetition benefited the recall of both congruous and incongruous endings and reduced the amplitude and shortened the duration of the N400 component of the ERP more for (1) incongruous than congruous words, (2) open class than closed class words, and (3) low-frequency than high-frequency open class words. For incongruous sentence terminations, repetition increased the amplitude of a broad positive component subsequent to the N400.

Assuming additive factors logic and a traditional view of the lexicon, our N400 results indicate that in addition to their singular effects, semantic congruity, repetition, and word frequency converge to influence a common stage of lexical processing. Within a parallel distributed processing framework, our results argue for substantial temporal and spatial overlap in the activation of codes subserving word recognition so as to yield the observed interactions of repetition with semantic congruity, lexical class, and word frequency effects. ■

INTRODUCTION

In the word recognition literature, repetition priming generally refers to the facilitated processing of a word on second presentation relative to its first. Speed and accuracy improvements have been observed across a wide range of tasks including lexical decision (LDT), pronunciation, categorization, and perceptual identification (Dannenbring & Briand, 1982; Scarborough, Cortese, & Scarborough, 1977; Scarborough, Gerard, & Cortese, 1979; Feustel, Shiffrin, & Salasoo, 1983; Jacoby, 1983; Jacoby & Dallas, 1981; Jacoby & Witherspoon, 1982). Facilitated processing also has been obtained with each of these tasks when prime and target are semantically associated rather than identical (Becker, 1980; Fischler & Bloom, 1979; Meyer & Schvaneveldt, 1971; Neely, 1977; Stanovich & West, 1983). Naturally, there has been some question as to whether or not a single mechanism can subserve both priming effects.

Traditionally, both semantic and repetition priming effects have been interpreted in terms of Morton's (1970) "logogen" model of word recognition. Within this framework, each word in the mental lexicon is represented by a logogen with an all-or-nothing threshold. A logogen is presumed to accumulate evidence until its activity level exceeds threshold, thereupon making available a full specification of the matching word's structure and meaning. Consequent to a logogen's firing, either its resting activation level increases or its threshold decreases for some time thereafter (from most perspectives these alternatives are indistinguishable). It is this change in a logogen's activation-to-threshold level that has been invoked to account for both word frequency and repetition priming effects. In as much as one logogen's firing is presumed to alter the activities of associatively or semantically related logogens via automatic spreading activation (e.g., Collins & Loftus, 1975), a change in a logogen's resting activity level or threshold also has been proposed as a mechanism of semantic priming.

According to additive-factors logic (Sternberg, 1969), the logogen model would predict an interaction between semantic and repetition priming effects because both are produced by the same underlying process. However, the results of the few studies that have directly compared behavioral measures of semantic and repetition priming favor additivity rather than interaction (Dannenbring & Briand, 1982; den Heyer, Goring, & Dannenbring, 1985; Wilding, 1986). Repetition and semantic priming effects have been reported to diverge in several other respects as well. For instance, repetition effects persist longer, enduring across many intervening items and long stretches of time (Scarborough et al., 1977; Feustel et al., 1983; Jacoby & Dallas, 1981). Repetition effects are typically stronger than semantic priming effects as well. Such results have suggested that different processes underlie semantic and repetition priming effects (Dannenbring & Briand, 1982; Wilding, 1986).

A similar conclusion was ultimately arrived at by Rugg (1987) on the basis of event-related brain potential (ERP) measures of semantic and repetition priming (but see also Rugg, 1985, for an earlier account). Rugg found that both related and repeated words elicited less negativity in the ERP between 250 and 600 msec postword onset relative to unprimed words (see also Bentin, McCarthy, & Wood, 1985; Halgren & Smith, 1987; Rugg, 1985, 1987; Smith & Halgren, 1989). Nonetheless, Rugg (1985, 1987) has maintained that this generic resemblance is misleading and that wholly distinct cognitive processors are engaged by semantic and repetition priming. To support his assertion, Rugg has pointed to the larger size, more equipotential distribution across the scalp, occasionally earlier onset and generally longer duration of word repetition as opposed to semantic priming ERP effects.

In both ERP and behavioral studies, the focus of semantic and repetition priming effects has been on the processing of single words appearing in pairs or in word lists. To our knowledge, very few investigators have compared semantic and repetition priming effects for words embedded in sentence contexts (Bobrow, 1970; Rothkopf & Coke, 1966; Thios, 1972). The results of those that have, however, indicate that it may not be valid to generalize from isolated word lists to sentences. For example, Bobrow (1970) and Thios (1972) both observed that the magnitude of the repetition effect was influenced by the nature of the sentence context in which the words were repeated (e.g., same, similar, or different). Thus, in contrast to the additivity observed for words in lists, semantic and repetition priming effects for words in sentences were found to interact. Perhaps semantic and repetition priming reveal different patterns of interactions in word and sentence contexts because each factor alone behaves differently in word lists than in sentential contexts.

Indeed, it is a matter of considerable controversy whether the mechanism of lexical priming is one and the same as that underlying sentential priming (see Henderson, 1982). A few investigators have assessed the impact of varying the proportion of related words, or congruent sentences, within an experiment (for word pairs see DeGroot, 1984; Den Heyer, Briand, & Dannenbring, 1983; Tweedy & Lapinski, 1981; Tweedy, Lapinski, & Schvaneveldt, 1977; Seidenberg, Waters, Sanders, & Langer, 1984; for sentences see Sanocki & Oden, 1984; Fischler & Bloom, 1985; Stanovich & West, 1983, expt. 4). On balance, the results suggest that the lexical decision task is sensitive to proportionality while the pronunciation task is not, but the data have revealed little difference between single word and sentence contexts.

One factor that has been emphasized in the distinction between single word and sentence contexts is the time courses of their priming effects. Lexical priming effects obtained in lists of words are short-lived, virtually eliminated by an interval of a few seconds or a word interposed between the target and associated prime (Monsell, 1985; Ratcliff, Hockley, & McKoon, 1985). However, three recent reports have detailed long-lasting effects of lexical priming within sentences or sentence-like stimuli (Simpson, Peterson, Casteel, & Burgess, 1989; O'Seaghdha, 1989; Van Petten, 1989). Clearly, the extent to which different mechanisms may underlie semantic priming in single word and sentence contexts and how these may be influenced by repetition is a matter for further empirical investigation using on-line, noninvasive measures of word processing.

The present experiments capitalized on the sensitivity of ERPs to both semantic congruity and repetition. Two experiments were designed to determine how repetition influences the processing of semantically congruent versus anomalous sentence terminal words and their memorability. Sentences that ended either congruously or incongruously were repeated once (Experiment 1) or twice (Experiment 2) and followed by a recall test in which the sentence fragment served as a cue for the final word.

Previous work has shown that the ERP is very sensitive to the presence of a semantically incongruent word in a sentence (e.g., Kutas & Hillyard, 1980). The primary difference between the ERPs to semantically congruent and incongruent words is the presence of a monophasic negativity between 250 and 600 msec (i.e., the N400 effect), which is larger in response to incongruities. While semantic incongruities yield the largest N400s, several studies have demonstrated that all words elicit an N400 component, the amplitude of which is inversely proportional to that word's expectedness within its context (Kutas & Hillyard, 1984; Kutas, Lindamood, & Hillyard, 1984). Existing evidence suggests that lexical associations, sentential constraints, and word frequency all contribute to determine the amplitude of the N400 component (Fischler et al., 1983; Van Petten & Kutas, 1990, 1991; Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991). It has been assumed that the N400 elicited by semantic anomalies occurring in sentences is essentially the same component as that seen with priming manipulations in lexical decision (Bentin et al., 1985; Holcomb, 1988; Holcomb & Neville, 1990; Rugg, 1985, 1987), verification (Fischler et al., 1983), and category judgments (Boddy & Weinberg, 1981; Polich, Vanasse, & Donchin, 1981; Rugg, Furda, & Lorist, 1988).

While the results of the behavioral and electrophysiological studies reviewed above suggest that semantic priming and repetition effects may sometimes differ, the possible overlap in one or more of the mechanisms underlying these two types of priming has not been ruled out (e.g., Henderson, 1982; Monsell, 1985). Thus one of our goals in recording ERPs to congruous and incongruous words in sentences was to extend the observations on the relation between semantic and repetition priming from single word to sentence contexts. Based on previous results we anticipated (1) that incongruous words would elicit larger N400s than congruous ones on initial presentation and (2) that repetition of these words would reduce the amplitude of the negativity in the region of the N400. The question of interest was whether or not repetition would influence the processing of congruous and incongruous words equally; that is, whether the semantic congruity and repetition effects were additive or interactive. The question was also examined with reference to cued recall performance.

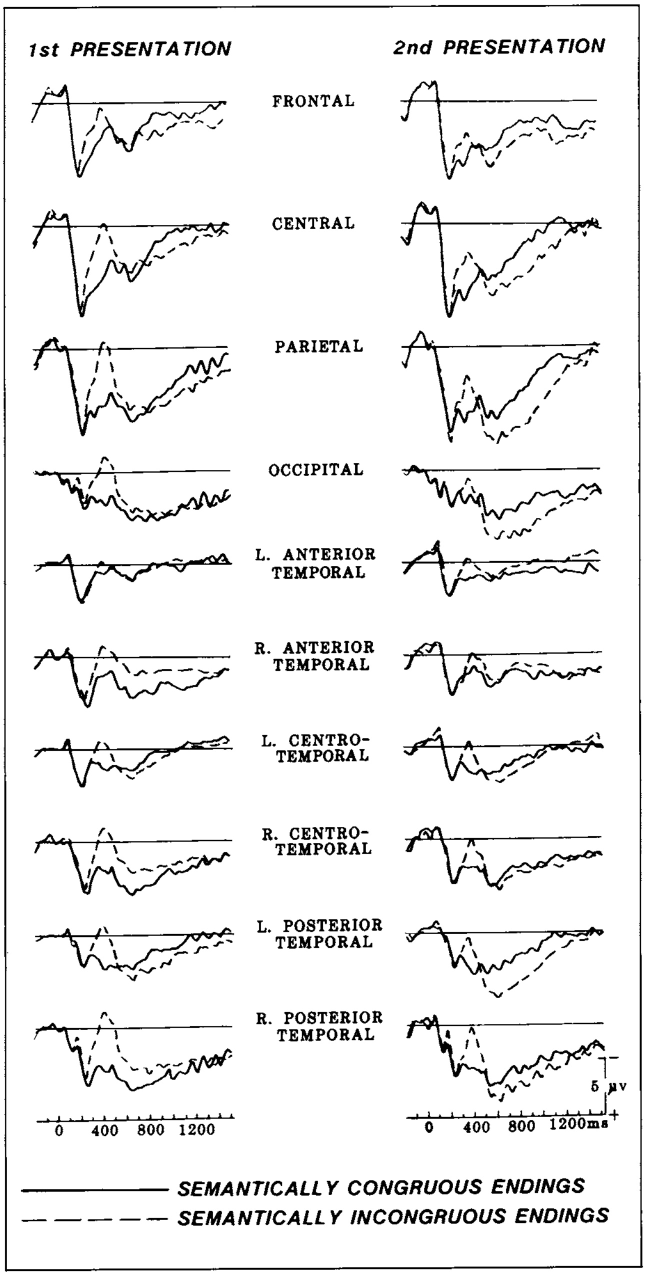

Figure 1. Grand average ERPs ($N = 17$) for semantically congruous and incongruous endings on first and second presentations of the 160 sentences in Experiment 1. Unless otherwise indicated, in this and subsequent figures ERPs presented were recorded at frontal (Fz), central (Cz), parietal (Pz), occipital (Oz), left anterior temporal (Broca's area), right anterior temporal (Broca's homolog on the right hemisphere), left centrotemporal (Brodmann area 41), right centrotemporal (Brodmann area 41), left posterior temporal (Wernicke's area), and right posterior temporal (Wernicke's homolog on the right hemisphere). On this and subsequent figures negative is up.

RESULTS

Experiment 1

Cued-Recall Performance

Across blocks, an average of 45% of the 160 total sentence terminal words was recalled. Semantically congruous endings were better recalled than incongruous ones on both the initial (60% versus 6%) and second (87% versus 26%) presentations. A two-way analysis of variance (ANOVA), including congruity and repetition as repeated measures revealed significant main effects of both congruity [$F(1,16) = 402.0$, $p < .001$] and repetition [$F(1,16) = 225.3$, $p < .001$] and a marginally significant interaction between the two [$F(1,16) = 3.7$, $p < .07$].

Event-Related Potential (ERP) Analyses

Grand average ERPs elicitéd by congruous and incongruous terminal words during the first and the second presentations are shown in Figure 1. On initial presentation incongruous words elicited a much larger N400 than did congruous words, with repetition reducing the N400 to incongruous words and the relative difference between congruous and incongruous ERPs in the N400 region. Another effect of repetition, similarly more evident in the response to incongruous words, was the enhancement of a late positive wave following the N400.

Quantitative measurements of individual subject waveforms were made relative to a prestimulus baseline by computing the mean voltage in two latency windows following terminal word onset: one corresponding to the typical latency of the N400 component, 300 to 600 msec (e.g., Kutas, Van Petten, & Besson, 1988) and a later one between 600 and 1300 msec. The Greenhouse–Geisser correction for inhomogeneity of variance was applied where appropriate.

Repetition and Semantic Congruity Effects in the N400 Latency Band

An overall ANOVA for the 300 to 600 msec measure including congruity, repetition, and electrode location as factors yielded significant main effects of congruity [$F(1,15) = 11.2, p < .004$] and repetition [$F(1,15) = 11.1, p < .004$], as well as an interaction between the two [$F(1,15) = 5.4, p < .03$]. Separate analyses of the two blocks showed that the difference between congruous and incongruous words was significant only on initial presentation [main effect of congruity, first presentation: $F(1,15) = 18.4, p < .001$, second presentation: $F(1,15) = 1.2, p > .10$]. Separate analyses for each of the ending types across the two blocks revealed that incongruous completions [$F(1,15) = 24.3, p < .001$] but not congruous ones [$F(1,15) = 1.09, p > .10$] were influenced by repetition in the N400 latency range. In sum, the congruity by repetition interaction in the overall ANOVA reflects a reduction in negativity for incongruous words, in the face of invarying ERPs to congruous words.

Scalp Distribution of the Repetition and Semantic Congruity Effects in the N400 Latency Range

As only incongruous words showed an ERP effect of repetition in the N400 latency range, we restricted our comparison of the topographies of the two priming effects to the congruity effect on initial presentation versus the repetition effect for incongruous words. Both the congruity and repetition effects were maximal over centroparietal and right hemisphere locations (Figure 2). Both effects were significantly larger over the right than the left hemisphere [for 300–600 msec, congruity by hemisphere, $F(1,15) = 13.7, p < .002$; repetition by hemisphere [$F(1,15) = 4.94, p < .04$]. A direct comparison of the scalp distributions of the congruity and repetition effects (measured in the difference wave ERPs) yielded no significant differences between them, whether analyses were performed on original or normalized measures.

Figure 2 suggests that the congruity effect began earlier than the repetition effect; it was already significant in the

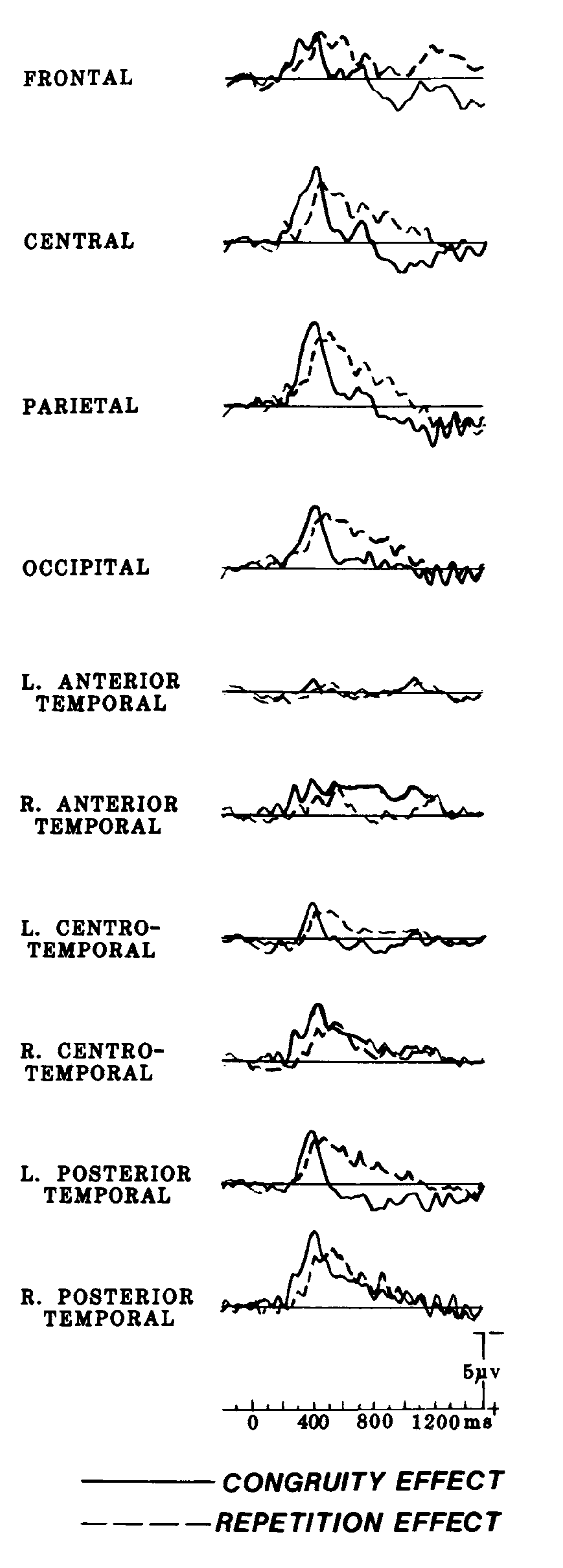

Figure 2. Overlapped are the ERPs difference waves illustrating the congruity effect (incongruous minus congruous endings) on first presentation, and the repetition effect (first minus second presentation) for incongruous endings in Experiment 1.

200–300 msec range [$F(1,15) = 5.1, p < .03$; congruity by hemisphere, $F(1,15) = 10.6, p < .005$] whereas the repetition effect was not [$F(1,15) < 1$].

Repetition and Semantic Congruity Effects in the LPC Range

An overall ANOVA of the 600– to 1300–msec latency band revealed no main effects but a significant interaction between congruity and repetition [$F(1,15) = 8.5, p < .01$]. Separate analyses of the two blocks revealed that between 600 and 1300 msec the ERPs to congruous and incongruous words were significantly different only when repeated [first presentation: $F(1,15) < 1$; second presentation: $F(1,15) = 9.3, p < .008$]. Congruous word ERPs were less positive over the right hemisphere on second relative to first presentation [repetition by laterality, $F(1,15) = 9.3, p < .008$]. In contrast, incongruous word ERPs exhibited a significant increase in the amplitude of the LPC with repetition [$F(1,15) = 4.4, p < .05$]; this effect was equipotential along the anterior–posterior dimension [$F(3,45) = 1.6, p > .10$] and bilaterally symmetric [$F(1,15) < 1$].

Repetition by Latency Window Analyses

The similarity of the repetition effects in the two latency bands (300–600 and 600–1300 msec) was assessed via an ANOVA including repetition and latency window as factors. For incongruous words, the repetition effect was significantly larger in the early (1.75 uv) than in the late (0.56 uv) part of the ERP [$F(1,15) = 17.1, p < .001$]. For congruous words, the repetition effect was equivalent across the two latency windows [$F(1,15) = 3.4, p > .05$].

Cross-Correlations

The similarity in waveshape between various ERP effects independent of the size of the effect was assessed by cross-correlations for vertex (Cz) recordings. Thus, a point-to-point comparison of two waveforms is capable of detecting a change in one of the waveshapes, due, for instance, to addition or deletion of a particular component within a particular time region, independent of positive or negative shifts extending uniformly through the entire epoch of interest. In the present case, we are interested in determining whether or not the N400 initially present in the incongruous waveforms is "deleted" or reduced by repetition so that these will more closely resemble the congruous waveforms that elicited little N400 activity in either presentation.

Comparisons of the ERPs elicited by the first and second presentations showed that for congruous words, cross-correlations were very high for both the 300–600 msec range (.92) and the 600–1300 msec range (.95). For incongruous words, cross-correlations were higher in the 600–1300 msec range (.95) than in the 300–600 msec range (.78).

Discussion

Our cued-recall memory data replicate findings in the literature in several respects (Bobrow, 1970; Kleiman, 1980; Schulman, 1974; Thios, 1972): (1) congruous endings were better recalled (73%) on the average than incongruous endings (16%) and (2) recall improved significantly with repetition from 33 to 56%. Finally, we found that the benefit conferred by repetition on recall performance was about the same for congruous (26%) and incongruous (21%) endings, although there was a slight tendency toward an interaction. This last finding extends the reported additivity of semantic priming and repetition effects in single word contexts to cued-recall of sentence final words.

One aspect of our data is problematic, however. Insofar as our congruous words were highly predictable, we cannot rule out the possibility that our subjects were guessing rather than retrieving words from memory on some proportion of trials. As this same strategy could not be applied equally to recall of incongruous words, the apparent equivalence in the improvement of recall performance for congruous and incongruous words following repetition may nonetheless reflect activity of different processes. To avoid the potential influence of a guessing strategy, less predictable congruous sentences were included in Experiment 2.

As expected, on initial presentation incongruous endings elicited significantly larger N400s than did congruous endings. The scalp distribution of this "N400 effect" corresponded to those of previous reports, being maximal parietally and larger for right than left hemisphere recordings (Bentin et al., 1985; Besson & Macar, 1987; Fischler et al., 1983; Kutas & Hillyard, 1980, 1982). The N400 congruity effect was noticeably smaller after only one repetition of all sentences primarily due to changes in the ERPs to incongruous endings. For incongruous words only, repetition was associated with an increase in a positive-going shift lasting from 300 to 1300 msec after stimulus onset; analyses showed this positivity to comprise at least two distinct phases (see below). Thus, repetition effects and congruity clearly interacted in the ERP response.

The interaction in the 300–600 msec epoch suggests that the congruity and repetition effects have at least one underlying process in common. Both the accumulation of contextual constraints and repeated exposure of words in a sentence modulate the amplitude of the N400 elicited by sentence final incongruous words. In the present experiment, the somewhat earlier onset and shorter duration of the congruity than the repetition effect suggest that perhaps sentential constraints act more efficiently than repetition to engage the operation reflected in the decreased N400 amplitude. In this regard, however, it is important to remember that the contextual constraints act locally within sentences and that these sentences were designed to be of high constraint. This was in contradistinction to the repetition effect, which was assessed over a lag of 160 sentences encompassing 45 min or so. Perhaps immediate repetition of sentences would shorten the onset of the ERP repetition effect.

The consequences of repetition on the ERP were not unitary; repeated exposure of incongruous endings was associated with both a diminution of the N400 and an enhancement of a subsequent late positive component (LPC). This view rests on our belief that the decrease in the amplitude of the N400 cannot be accounted for simply in terms of overlap by the ensuing LPC. In support of this conviction we offer the following arguments. First, the repetition effect did not exhibit a consistent topography throughout its duration; the topography of its initial extent between 300 and 600 msec mirrored that of the semantic congruity effect. The latter half of the repetition effect, 600–1300 msec, had a scalp distribution that was different from both the congruity effect and the early phase of the repetition effect. Second, we observed that the increase in positivity (or decrease in negativity) with repetition was significantly larger in its early than its later phase. Third, our correlational analyses indicated that independent of the amplitude modulations, the ERP was differentially sensitive to the repetition manipulation with the 300 to 600 msec region showing greater variation than the later phase, especially for incongruous endings. These facts support the claim that the semantic congruity effect and the early phase of the repetition effect were both due to changes in N400 amplitude whereas the later phase was due to a change in a distinct late positive component (see also Van Petten et al., 1991 for a dissociation between the N400 and late positive repetition effects).

Rugg (1985, 1987) has conducted a series of studies examining ERP repetition effects in word lists. The results of these studies are similar to ours in showing that both semantic and repetition priming reduce the amplitude of the ERP in the region of the N400. As in the present data set, Rugg (1985) also found that the ERP repetition effect is temporally more extended than the semantic priming effect; the duration of the repetition effect in Rugg (1987) is difficult to evaluate given that the recording epoch ended before the ERPs returned to baseline. Finally, Rugg likewise found the latter half of the repetition effect to be equipotential across the scalp as long as the repeated item did not also serve as a P3-eliciting target event (as in Rugg, 1987, but not Rugg, 1985).

However, other aspects of Rugg's findings differ from ours. First, Rugg reported larger effects of repetition than semantic priming whereas we observed the reverse. Perhaps this reflects the relatively shorter lag between repetitions in Rugg's than in our experiment or that a highly constraining sentence fragment provides a stronger semantic context than a single word prime. Second, in Rugg's (1987) data, the semantic priming ERP effect had a frontal maximum in marked contrast with the centroparietal maximum in the present data. Third, in some, although not all, of his studies, Rugg found an early repetition effect, reflected in a transient increase in negativity around 200 msec after stimulus onset (Rugg, 1987). We observed no effect of repetition with this polarity. These differences may be due to the nature of the context in the two experiments: words in lists versus sentences.

Based on the amplitude, duration, and scalp distribution differences in the ERPs elicited by semantic priming and repetition manipulations, Rugg (1987) suggested that they reflect engagement of different cognitive mechanisms. Our results, while supporting some distinction between these two types of priming effects, also suggest a common underlying process. Our results clearly indicate an interaction between congruity and repetition. Within the additive-factors framework, this result would mean that there is at least partial overlap in the process of semantic priming and repetition.

However, before considering the implications of our results and how they differ from those reported for word list experiments, we report the results of a second experiment designed to examine the generality of our findings and to resolve the inconsistency between the ERP and cued-recall results by reducing the influence of guessing strategies in the cued-recall task. From a theoretical perspective it is important to see whether the ERP differences between congruous and incongruous words will disappear with more repetitions. If the effect of word repetition is to increase the activation level of the corresponding logogens, then one might expect that additional repetitions would equate the activation levels of congruous and incongruous word logogens such that the ERP differences between the two would vanish. To test this possibility, sentences were repeated twice in Experiment 2.

Experiment 2

Only a few studies have examined the effects of weak sentence contexts, that is, when the beginning of a sentence is not predictive of the upcoming final word (Forster, 1981; Sanocki & Oden, 1984). Kutas and Hillyard (1984) showed that terminal congruous words completing sentences of low contextual constraints (i.e., words with low cloze probabilities) elicit N400 components intermediate in amplitude between that elicited by congruous words in highly constrained sentence contexts (i.e., words with high cloze probabilities) and incongruous words. Thus, analysis of the repetition effect for terminal words in sentences of varying contextual constraints may winnow the list of possible explanations for the lack of ERP repetition effects for congruous words in Experiment 1.

We also decided to examine the possible cumulative effects of multiple repetitions on the ERP congruity effect and on cued-recall performance. In Experiment 2, each sentence was repeated twice. Based on the results of Experiment 1, the N400 difference between congruous and incongruous words was expected to disappear with repetition. It is interesting to note that within the large behavioral literature on repetition effects, the impact of multiple repetition has been little studied. To the extent that it has, the bulk of the beneficial consequences of repetition seems to be spent with the initial repetition. For instance, Forbach, Stanners, and Hochhaus (1974) reported a large decrease in lexical decision time with one repetition, but no further facilitation with two or three repetitions. Accordingly, we might expect ERP signs of repetition to be relatively slight after the first repetition.

In this experiment we also examine the ERP repetition effects for sentence intermediate words. In particular, we compare the possibly different effects of repetition on open (e.g., nouns, verbs, adjectives and adverbs) and closed class (e.g., articles, prepositions, conjunctions, auxiliaries, pronouns) words. Almost all of the published data on repetition effects has been limited to open class words. Thus, we had little basis for a prediction other than the fact that closed class items are by their nature repeated more often both within and between sentences. Since any observed difference between the repetition effect for open and closed class words could be attributed to different frequencies of occurrence we also planned to examine the effect of repetition on the ERPs elicited by high- and low-frequency words. A subset of open class words was used in the frequency analysis, namely, the subjects and main verbs of the main clause in each sentence. "High" and "low" frequency were defined as greater or less than 80/million by the Kucera and Francis (1982) count. With few exceptions (e.g., Humphreys, Besner, & Quinlan, 1988), behavioral measures of repetition have shown a greater benefit of repetition for low- than high-frequency words (Scarborough et al., 1977; Jacoby & Dallas, 1981; Forster & Davis, 1984; Ducheck & Neely, 1989). Accordingly, we might expect to observe larger ERP repetition effects for low-frequency words.

Cued-Recall Performance

Cued-recall performance for congruous and incongruous sentence final words for the three presentations is presented in Table 1. Overall, subjects recalled an average of 42% of the 184 last words. A three-way ANOVA, including congruity (congruous versus incongruous), context (high, medium, and low constraint), and repetition (first, second, and third presentation) as repeated measures, revealed significant main effects of congruity [$F(1,15) = 317.8, p < .0001$], context [$F(2,30) = 9.9, p < .001$], and repetition [$F(2,30) = 122.2, p < .0001$].

Among the two-way interactions, the congruity by repetition [$F(2,30) = 6.2, p < .005$] and the congruity by context [$F(2,30) = 11.9, p < .001$] interactions were significant. The three-way congruity by context by repetition interaction was also significant [$F(4,60) = 2.7, p < .03$]. However, the context by repetition interaction did not reach significance [$F(4,60) = 2.5, p < .10$], although post hoc Tukey comparisons showed that for congruous words, the differences between high/medium and low constrained sentences were significant for both the first (15.4%, $p < .01$) and second presentations (10.9%, $p < .01$), but not for the third presentation. No difference was found for incongruous words. Post hoc comparisons also revealed that the increase in performance with repetition was larger for congruous (30.9%) than for incongruous (13.6%) words, but the increase with the second repetition was similar for congruous (13.7%) and incongruous (15.5%) words. For congruous words, the mean difference between medium and low degrees of contextual constraints was 11.5% and virtually no difference (0.8%) was found between high and medium constrained contexts. As expected, no effect of context was found for incongruous words.

Event-Related Potential Analyses

Grand average ERPs elicited by congruous and incongruous terminal words during the first, second, and third presentations are presented in Figure 3. Incongruous words elicited larger N400 components than congruous words on first presentation. This difference was attenuated on second presentation and vanished completely on third presentation. In contrast, the LPC elicited by incongruous words was enhanced by the first and second repetitions. To compare results, the same analyses were conducted for Experiment 2 as for Experiment 1.

Repetition and Semantic Congruity in the N400 Latency Band

An overall ANOVA for the 300- to 600-msec latency band, including congruity (congruous versus incongruous), repetition (first, second, and third presentations), and electrode location as factors showed that the main effect of congruity was not significant [$F(1,15) = 2.5, p > .10$]. The main effect of repetition [$F(2,30) = 6.0, \epsilon = .66, p < .02$] was significant, as was the interaction between con-

Table 1. Percent Cued Recall of Sentence Final Words

	Congruous				Incongruous			
Block	*$\bar{x}$(sd)*	*high*	*medium*	*low*	*$\bar{x}$(sd)*	*high*	*medium*	*low*
1	44(19)	49	49	33	2(2)	2	2	2
2	74(18)	77	79	67	15(13)	18	14	15
3	88(12)	90	91	84	31(23)	36	27	31

High, medium, and low refer to degree of contextual constraint of sentence fragments.

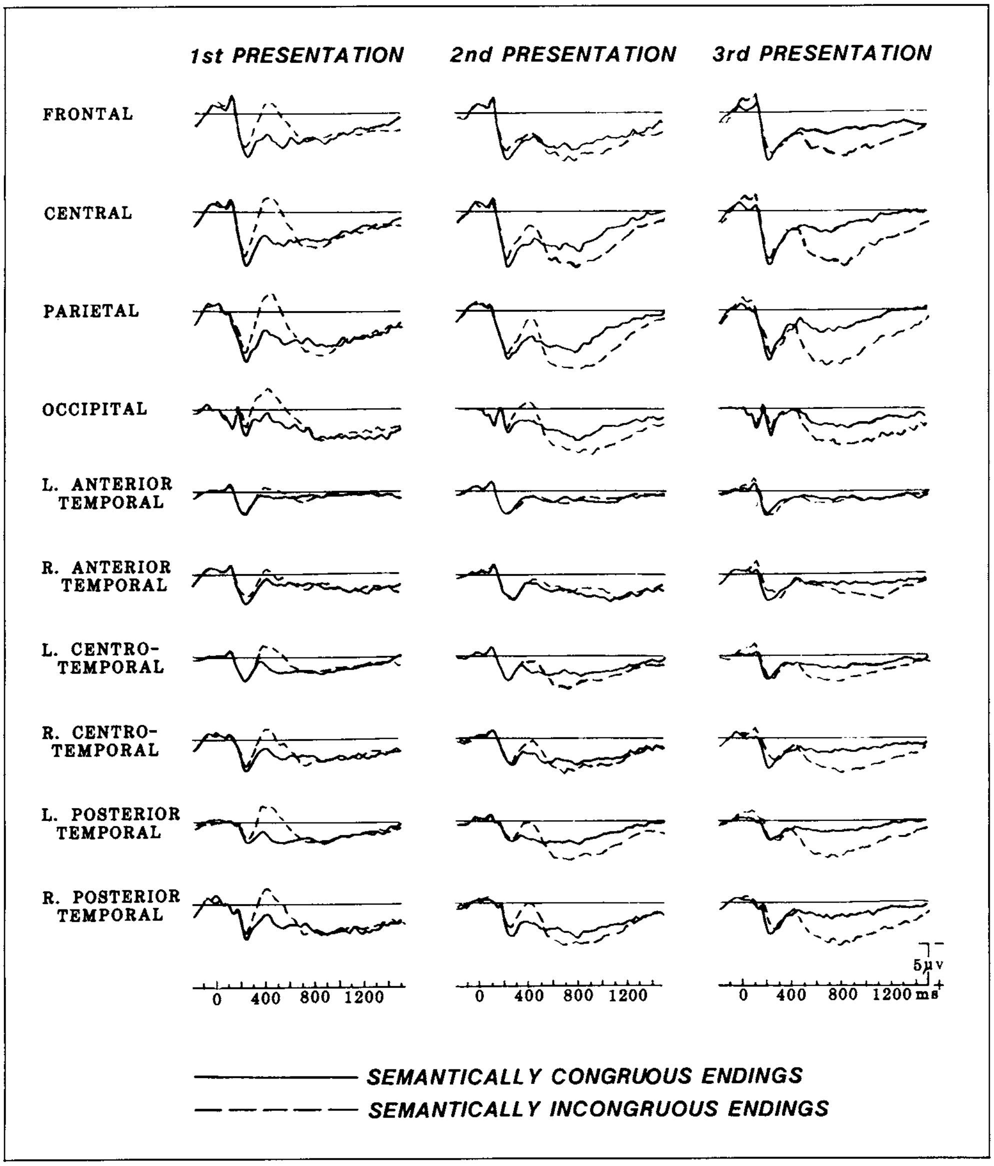

Figure 3. Grand average ERPs ($N = 16$) for semantically congruous and incongruous endings on first, second, and third presentations of the 192 sentences in Experiment 2.

gruity and repetition [$F(2,30) = 10.0$, $\epsilon = .71, p < .004$]. Separate analyses of the three presentations showed that the ERPs elicited by congruous and incongruous words differed significantly only on initial presentation [main effect of congruity, first presentation: $F(1,15) = 9.6, p < .007$; second presentation: $F(1,15) < 1$; and third presentation: $F(1,15) = 4.1, p > .05$]. Separate analyses of the ERPs elicited by congruous words showed that only the difference between the second and third presentations was significant [$F(1,15) = 7.6, p < .01$; first versus second presentations: $F(1,15) < 1$]. In contrast, incongruous words differed significantly on first and second presentations [$F(1,15) = 29.2, p < .001$], but not on second and third presentations [$F(1,15) < 1$].

Scalp Distribution of the Repetition and Semantic Congruity Effects

As in Experiment 1, both the congruity effect on first presentation and the repetition effect for incongruous words were larger at more posterior electrodes [first versus second presentation, repetition by anterior–posterior: $F(3,45) = 6.9$, $\epsilon = .41$, $p < .01$]. Like Experiment 1, the pattern of lateralization for both effects was the same; however, unlike Experiment 1, both effects were bilaterally symmetric (Figure 4). Similarly, the repetition effect for incongruous words was larger posteriorly than frontally [first versus second presentation, repetition by anterior–posterior: $F(3,45) = 6.9$, $\epsilon = .41$, $p < .01$], but was not asymmetric [repetition by laterality: $F(1,15) = 1.6$].

Onset Latency of Repetition and Semantic Congruity Effects

Comparison of the onset latency of the congruity effect on first presentation and of the repetition effect for incongruous words showed no significant difference in the 200- to 300-msec latency band [congruity effect: $F(1,15) = 2.8$, $p > .10$; repetition effect: first versus second presentation, $F(1,15) = 3.9$, $p > .05$]. Thus, the two effects did not show different onsets as they did in the first experiment.

Repetition and Semantic Congruity Effects in the LPC Latency Band

An overall ANOVA of the 600- to 1300-msec latency band showed a significant main effect of congruity [$F(1,15) = 7.4$, $p < .01$], and an interaction between congruity and repetition [$F(2,30) = 4.5$, $p < .02$]. Separate analyses were done to elucidate the interaction. These showed no congruity effect on first presentation [$F(1,15) < 1$], but that the LPC on second and third presentations was larger for incongruous than congruous words [second: $F(1,15) = 4.6$, $p < .04$; third: $F(1,15) = 16.3$, $p < .001$]. Note that the LPC congruity effect on second presentation was not large; if first and second presentations are analyzed together as in Experiment 1, there is no significant main effect of congruity [$F(1,15) = 1.2$]. Analyses of the repetition effect on congruous words showed that it was not significant either from the first to second [$F(1,15) < 1$] or second to third presentations [$F(1,15) = 3.2$]. In contrast, analyses of the incongruous words revealed an enhancement of the late positivity between the first and second presentations [$F(1,15) = 7.2$, $p < .01$], which was bilaterally symmetric [repetition by laterality: $F(1,15) = 2.7$] and equipotential in the anterior–posterior dimension [repetition by anterior–posterior: $F(1,15) = 1.5$]. Thus, unlike the distribution of the N400 to incongruous words in the 300- to 600-msec window, the late positivity was not larger posteriorly than frontally. The late positivity was of similar amplitude for the second and third presentations [$F(1,15) < 1$].

Repetition by Latency Band Interactions

It is of some interest to determine whether the effect of repetition is equivalent in the 300- to 600-msec (N400) and in the 600- to 1300-msec (LPC) latency bands. Analyses of the ERPs elicited by incongruous words showed that the repetition by latency band (300–600 versus 600–1300 msec) interaction was not significant for either the first versus second [$F(1,15) = 2.9$, $p > .05$] or for the second versus the third presentation comparisons [$F(1,15) = 1.3$, $p > .20$]. When these same comparisons were made for congruous words no significant interaction was found [first versus second presentation: $F(1,15) < 1$, and second versus third presentation: $F(1,15) < 1$].

Cross-Correlations

Finally, cross-correlations were computed for vertex (Cz) recordings. In the 300–600 msec range, the correlations between ERPs to congruous and incongruous words increased from the first (.52) to the second presentation (.70) but decreased from the second to the third presentation (−.17). These correlations were similar for each presentation in the 600–1300 ms range (first presentation $r = .83$; second presentation $r = .92$; third presentaton $r = .89$). For incongruous words, the correlations between the ERPs in the first versus second presentation, and between the ERPs in the second versus third presentation were high in both latency epochs. For congruous words, the cross-correlations were higher in the 600–1300 than 300–600 msec range.

Repetition Effects for Function and Content Words

As can be seen on Figure 5, the difference in the ERPs elicited by function and content words in the N400 latency range decreased with repetition due primarily to a reduction in the N400 elicited by content words. Accordingly, results of a three-way ANOVA in the 300–600 msec range, including repetition, word class (function versus content), and electrodes as factors, showed a significant repetition by word class interaction [$F(2,30) = 3.89$, $p < .03$]. Neither the main effect of repetition [$F(2,30) < 1$] nor of word class [$F(1,15) = 2.33$, $p > .10$] was significant. The ERP difference between function and content words in the 300–600 msec range was significant for the first presentation only [$F(1,15) = 7.67$, $p < .01$; second presentation: $F(1,15) < 1$; third presentation: $F(1,15) = 2.68$, $p > .10$]. For content words, the difference between the first and second presentations was

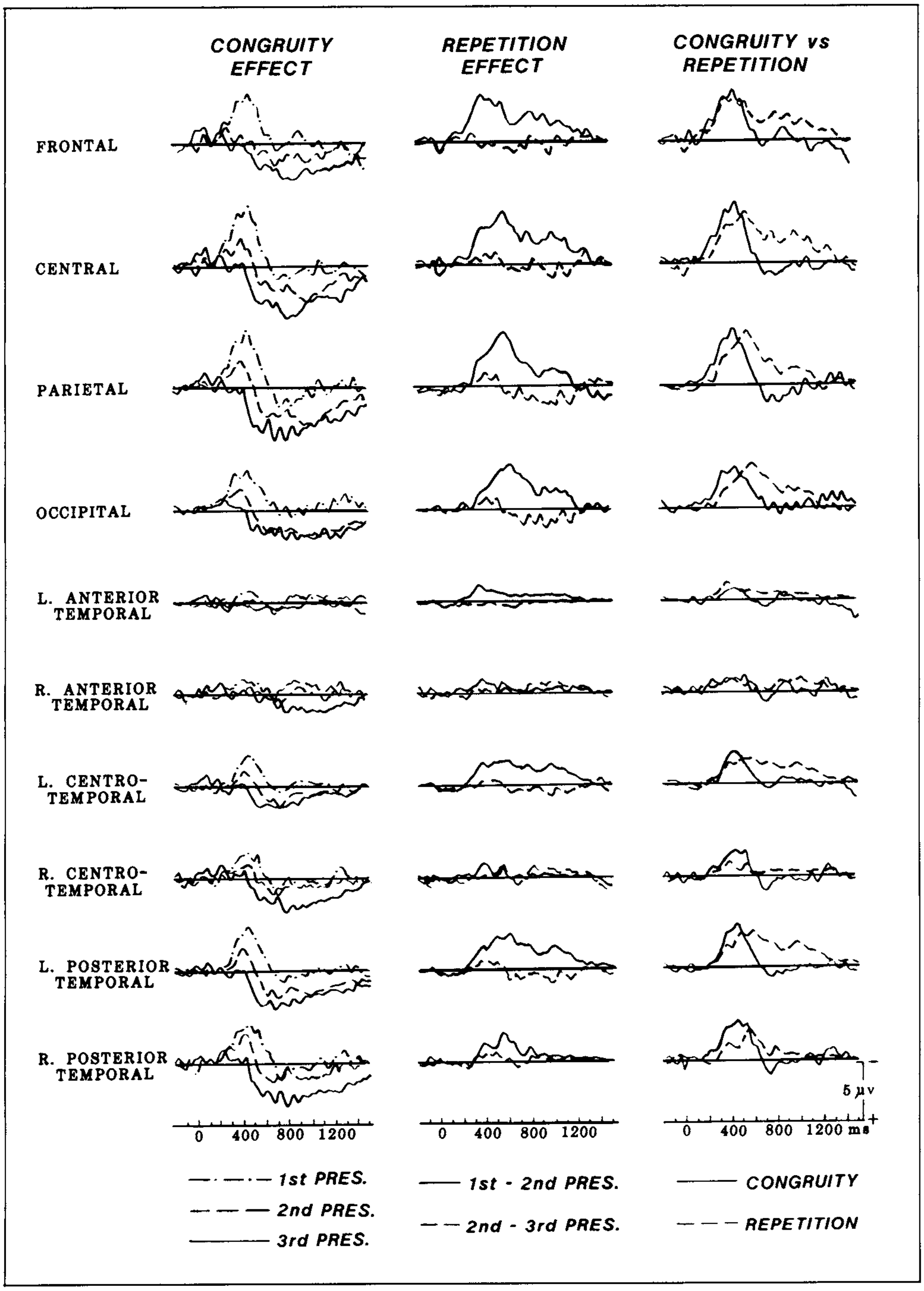

Figure 4. ERPs difference waves calculated for data from Experiment 2. In the left-hand column the congruity effect (incongruous minus congruous endings) for first, second, and third presentations of the sentences are overlapped. In the middle column, the effect of one repetition for incongruous endings (first minus second presentation) is compared to the effect of a second repetition (second minus third presentation). In the right-hand column the congruity effect on initial presentation is contrasted against the repetition effect (first minus second presentation) for incongruous words.

significant [$F(1,15) = 4.68, p < .05$] while the difference between the second and third presentations was not [$F(1,15) < 1$]. There were no significant repetition effects for function words.

Repetition Effects for High- and Low-Frequency Content Words

The ERPs elicited by the subjects and main verbs of the sentences differed as function of word frequency, with low-frequency words having a larger N400 than high-frequency words. This difference decreased with repetition (see Figure 6).

Results of a three-way ANOVA in the 300- to 600-msec band, including repetition (first, second, and third presentation), word frequency (high and low), and electrodes as factors revealed a significant main effect of repetition [$F(2,30) = 5.18, \epsilon = .74, p < .03$] but no main effect of frequency [$F(1,15) = 1.44, p > .20$]. The repetition by frequency interaction was significant [$F(2,30) = 3.93, \epsilon = .75, p < .03$]. The repetition effect was significant for both high- [$F(2,30) = 4.54, \epsilon = .96, p < .01$] and low-frequency words [$F(2,30) = 4.63, \epsilon = .82, p < .01$]. However, the

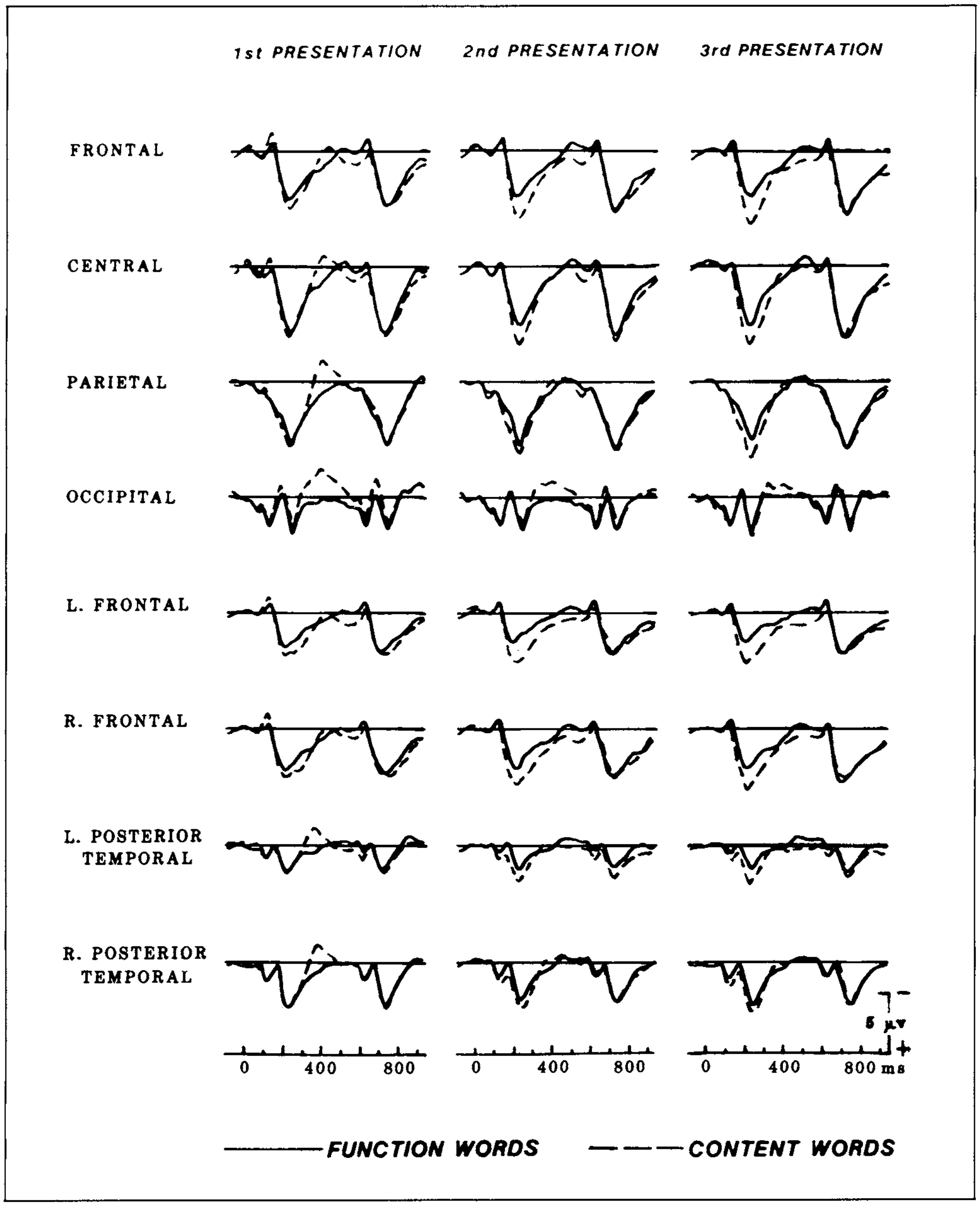

Figure 5. Grand average ERPs ($N = 16$) for content and function words on first, second, and third presentations in Experiment 2. Left frontal and right frontal recording sites correspond to F7 and F8 locations, respectively.

ERP difference between the first and second presentations was significant for low-frequency words [$F(1,15) = 13.98$, $p < .002$] but not for high-frequency words [$F(1,15) = 1.36$, $p > .20$]. In contrast, the ERP difference between the second and third presentation was significant for high-frequency words [$F(1,15) = 8.92$, $p < .009$] but not for low-frequency words.

Discussion

As in Experiment 1, the increase in cued-recall performance from the first to the second presentation was larger for congruous than incongruous words. However, in the first experiment this differential sensitivity to repetition was small and only marginally significant whereas in the second experiment repetition yielded a much larger increase in recall for congruous (31%) than incongruous (14%) words. The robustness of the interaction in Experiment 2 may suggest that when sentences with less predictable final words are presented and subjects cannot rely on guessing to retrieve congruous endings, an underlying mechanism shared by repetition and semantic priming is revealed.

While we would like to attribute the semantic congruity by repetition interaction in Experiment 2 to our contextual constraint manipulation, it is important to note that we also changed memory conditions. Unlike Experiment 1, where the subjects were forewarned of the cued-memory test, subjects were unaware of the memory demands until the second run of Experiment 2. The possible importance of the memory instructions for the type of congruity by repetition interaction observed is suggested by the fact that after the second experimental run when the cued-recall memory test was expected (inten-

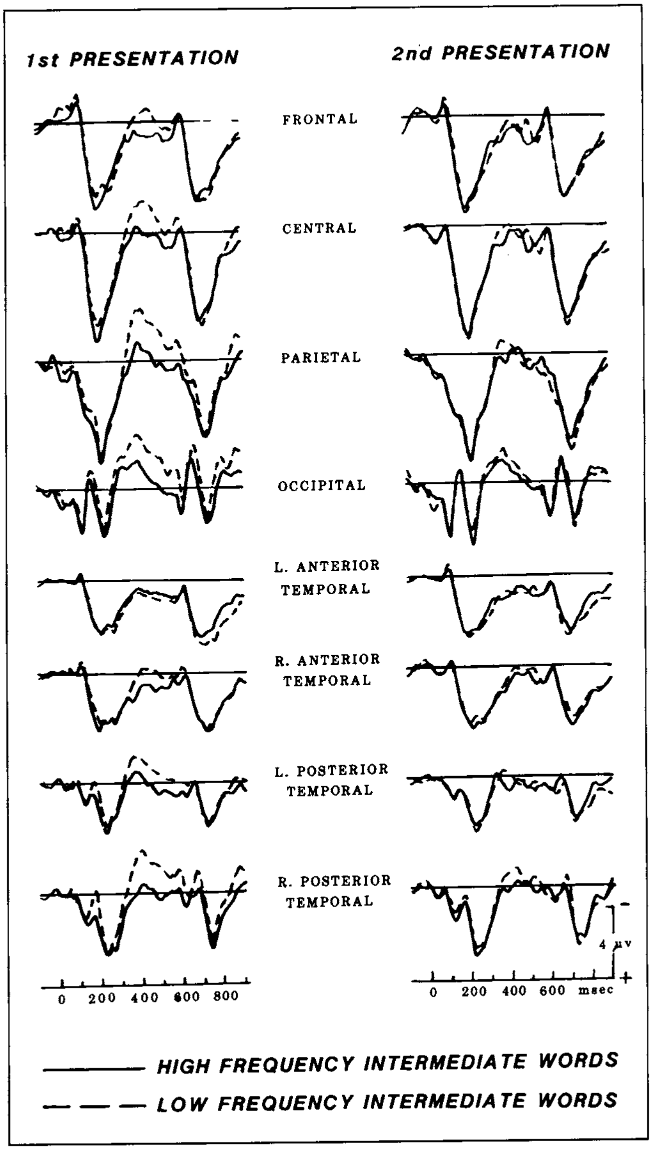

Figure 6. Grand average ERPs ($N = 16$) for sentence intermediate content words with high (greater than 80/million occurrences) and low (less than 80/million occurrences) frequency of occurrence in the English language on first and second presentations in Experiment 2.

tional recall) as in Experiment 1, semantic congruity and repetition no longer interacted as in the first run but were additive. That is, the increase in cued-recall performance with a second repetition was essentially the same for congruous (13.7%) as incongruous words (15.5%). It is thus possible that the effects of repetition and semantic congruity vary as a function of memory instructions (i.e., intentional versus incidental). Additional research is needed to compare the possible differential consequences of repetition and semantic priming with incidental and intentional learning instructions.

As for the behavioral results, the ERP results largely replicated those found in Experiment 1: (1) in the 300–600 msec range, the congruity effect was significant only on initial presentation; (2) in the 600–1300 msec range, the congruity effect became significant only after the sentences were repeated; (3) repetition had a larger effect on the ERPs to incongruous than congruous final words.

In addition to the basic congruity manipulation, Experiment 2 included a subtler manipulation of semantic context in the cloze probability factor. These results supported those of the congruity manipulation in that the N400 differences between the three levels of cloze probability were diminished by repetition (although the cloze probability by repetition interaction did not reach significance probably due to the small number of trials in each of these subconditions and correspondingly low signal-to-noise ratio). This result parallels the cued-recall measures since the difference between high/medium and low constrained sentences was significant after the first two presentations, but not after the third.

Are there any apparent benefits to more than one repetition?

The answer from the present behavioral and ERP data is a very weak "yes." Extra repetition conferred rapidly diminishing effects. Whether the measure be cued-recall performance, increasing amplitude of the positivity to congruous endings, decreasing amplitude of the N400 to incongruous endings, or the increasing amplitude of the LPC to incongruous endings, it is a negatively accelerated function of the number of recent encounters. A similar conclusion has been drawn by several other investigators on the basis of behavioral data (Monsell, 1985, 1991).

Effects of Repetition on Function and Content Word Class ERPs

Intermediate content words initially elicited larger N400s than intermediate function words, a finding apparent in several previous experiments (Garnsey, 1985; Kutas & Hillyard, 1983; Kutas et al., 1988; Van Petten & Kutas, 1991; Neville, 1992). With one repetition, however, this difference was eliminated because the N400 elicited by content words decreased whereas the N400 to function words was unchanged. We have recently argued that the basic difference in N400 amplitude between the two vocabulary classes is due to a combination of word predictability, frequency, and intrasentence repetition of closed class items (Van Petten & Kutas, 1991), rather than to any qualitative difference in lexical representations or retrieval procedures for the two vocabulary types (see Bradley & Garrett, 1983; Chiarello & Nuding, 1987; Gordon & Caramazza, 1982; Kolk & Blomert, 1985; Petocz & Oliphant, 1988; Roxenberg, Zurif, Brownell, Garrett, & Bradley, 1985; Segui, Mehler, Frauenfelder, & Morton, 1982). The present results suggest that the naturally occurring difference in the rate at which function and content words recur is indeed an important element for explaining their different N400 amplitudes. The same function words (e.g., "the," "a," "she," "was") reappeared in many of the experimental sentences and thus had a much higher de facto repetition rate than that defined by the experimental blocks; this was not true of the content words. The apparent dissociation between content and function words in their sensitivity to repetition is thus somewhat misleading, but it was informative to find that only a single repetition of content words within sentence contexts was sufficient to offset the naturally higher rate for function words. The lack of a repetition effect for function words is perhaps most informative as a confirmation of one of the other findings of the present experiment, namely that there is some "floor" to the N400 repetition effect; after a certain point, subsequent repetitions do not further reduce N400 amplitude.

Repeated presentations revealed an earlier effect most evident in content word ERPs, an apparent increase in the amplitude of the P2 component (between 180 and 220 msec) especially at frontal sites. A similar effect was recently observed in a study of naturally occurring repetitions in extended discourse (Van Petten et al., 1991), but the reliability of this early effect still needs to be validated given other reports of an early negative effect (Rugg, 1987; Nagy & Rugg, 1989), as well as some reports of no effect at all (Bentin & Peled, 1990; Rugg & Nagy, 1987, 1989). In contrast, the N400 and LPC have been consistently sensitive to repetition across a number of experiments.

Effects of Repetition on Processing of High- and Low-Frequency Content Word ERPs in Sentence Intermediate Positions

If we are correct in attributing part of the N400 difference between function and content words to their different frequencies of occurrence, then we would also expect to observe smaller N400s in the ERPs elicited by high- than low-frequency content words. Continuing this line of reasoning, we should also observe an interaction between repetition and word frequency for the N400 component of open class word ERPs. As in our previous experiments and as reported by others using word lists, the N400 was larger in amplitude for intermediate content words of low than high frequency. This frequency-related difference in N400, however, was attenuated severely by one repetition of the experimental sentences, that is, the ERP effects of word frequency and repetition interacted.

Our finding of an interaction of word frequency and repetition on N400 amplitude is reminiscent of the interaction between word frequency and semantic context on N400s elicited by content words in sentences and can be interpreted in a like manner (Van Petten & Kutas, 1990, 1991; Van Petten et al., 1991). In two separate experiments, the initial N400 frequency difference was eliminated as the semantic context accumulated. These findings were interpreted as evidence against any model of word recognition in which frequency played an obligatory role. The current data provide further support for this position by showing that word repetition also can override the use of a word's frequency in accessing its meaning.

In a word list experiment with a lexical decision task, Smith and Halgren (1987) likewise found that repetition eliminated the word frequency effect observed for initial exposures. Their procedure, however, involved three repetitions and did not allow a determination of the consequences of a single repetition. Rugg (1990) has compared the effects of a single repetition with a short delay (i.e., lag of six items) to that of a longer delay (i.e., 15 min). He too found that word frequency and word repetition interacted even after a single repetition. Prior to repetition, low-frequency words had slightly larger N400s and slightly smaller LPCs than did high-frequency words. On repetition at either delay in both tasks, the N400 difference disappeared while the LPC difference reversed in direction, primarily reflecting the increase in LPC amplitude for low-frequency words, much as we observed an increase in LPC amplitude for incongruous words with repetition. Rugg suggested that the post 500-msec ERP effect might index a mismatch between a low-frequency word's baseline familiarity and its new, local familiarity artificially inflated by the experimenter's intervention (i.e., repetition). For intermediate sentence words, we observed only an N400 repetition effect. It is possible that the relatively short interval between sentence words (500 msec) did not allow the engagement of those processes represented by the LPC, which begins at 500 to 600 msec poststimulus for both our sentence terminal words and Rugg's low-frequency list words. Another possibility is that the LPC repetition effect is not uniquely tied to repetition, but instead is related to a conscious retrieval strategy that subjects employ for repeated words in lists, but primarily for sentence terminal words in paradigms like the present one.

GENERAL DISCUSSION

One of the goals of the two experiments was to determine whether congruity and repetition would have interactive effects, suggesting a common functional locus, or not. It is thus crucial to know whether the repetition-induced positivity in the N400 latency range is due to a reduction in N400 amplitude for incongruous sentences, or due to the overlay of a positive component. The latter would suggest that congruity and repetition engage temporally overlapping, but independent processes. Three lines of evidence converge to argue for the former conclusion, that the N400 component is influenced by the congruity of a new sentence on first reading, and by the repetition of sentences that were (initially, at least) incongruent.

First, the repetition effect on incongruous words was larger in the N400 than the LPC latency windows, suggesting the modulation of two distinct components. Second, the scalp topography of the repetition effect was different in the two latency bands. In both experiments, the LPC window showed a repetition effect that was equipotential across the head. In the earlier N400 window, the repetition effect followed the distribution of the congruity effect: largest over central and parietal sites in both experiments, and larger over the right than the left in the first experiment. Finally, the cross-correlation analyses of the N400 latency window showed that the ERPs waveshape between congruous and incongruous words became more similar with repetition. A simple overlay of a broad positivity would not produce this last result; rather it suggests that the N400 itself was reduced by repetition.

The pattern of results thus demonstrates a commonality and a distinction between congruity effects, based on one's knowledge of a language, and repetition effects, based on recent experimental exposure. For the N400 component, there was a remarkable interaction between congruity and repetition: the difference between sensible and nonsensical words was reduced by one repetition and obliterated by a second. Thus, contrary to Rugg's (1987) conclusion that semantic priming and repetition priming are likely to rely on distinct cognitive mechanisms, the present data suggest one similar mechanism. However, repetition influenced a second component, which was distinct from the typical N400 congruity difference.

The Two Components to the Repetition Effect

The observation of two distinct repetition-sensitive ERP components is in accord with the conclusions drawn previously for repetition of words in lists (Halgren, 1990; Halgren & Smith, 1987; Rugg, 1990; Rugg & Nagy, 1989) and in text (Van Petten et al., 1991). The two effects have been observed not only in scalp recordings, but also intracranially in anterior and medial temporal lobes (Smith & Halgren, 1987; Smith, Stapleton, & Halgren, 1986). The modulation of the N400 by repetition consists of a decrease in amplitude in all situations where an N400 effect is observed. In lists, the N400 repetition effect has been shorter lasting (absent after a lag of more than 15 min) than the late positive effect (Fischler, Boaz, McGovern, & Ransdell, 1987; Rugg, 1990). In the present study, the lag time between repetitions of a given sentence was about 45 min. The persistence of the N400 repetition effect over this relatively long lag is likely to be due to the use of coherent sentences as opposed to isolated words.

Across studies, the behavior of the late positive component with repetition has been more variable. We have seen in the present study that the direction of its amplitude change was dependent on the congruity of the sentence. Both Rugg (1990) and Van Petten et al. (1991) found it to be more pronounced for low- than high-frequency words, although the direction of the amplitude change was different between the word list and the text study. Clearly, the LPC repetition effect will require further study before we have a clear picture of its functional significance.

In the present experiment, the late positive component was sensitive to congruity; it was enhanced by the repetition of incongruous words in both experiments. In the first experiment, repetition of congruous words resulted in a decrease of positivity in the 600- to 1300-msec latency region, and a similar (although not significant) trend was observed between the first and second repetitions of the second experiment. If we identify the repetition-sensitive positivity observed here with the late positivity elicited by successful recognition of repeated words (Neville et al., 1986), then we might speculate that repeated incongruous words were not "remembered" until they were, in fact, presented. But for congruous words, the preceding sentence fragments offered such strong cues that these final words might have been recalled sometime earlier in the sentence, before the final word actually appeared on the CRT screen. Thus, if there were a late positivity associated with the recognition of a repeated congruity, it might have appeared at different points during the preceding sentence fragment on different trials. In general, it is difficult to observe an ERP effect that is not consistently time-locked to an external stimulus, so this issue will be difficult to resolve.

Relation Between Word Repetition and Recognition Memory ERP Effects

Recall was substantially worse for incongruous than congruous words, as has typically been the case in other studies. In general, incongruous words also elicit larger N400s than congruous words. We might then want to suppose a link between the processes reflected by the N400 and those that support subsequent memory performance. However, in neither Experiment 1 nor Experiment 2 did N400 amplitude parallel the cued-recall performance across presentations. The N400 difference between congruous and incongruous endings was largely eliminated by repetition, but the differential recall of congruous and incongruous words remained much the same across presentations. To determine whether or not there is a direct link between N400 amplitude and memory, the ERPs must be averaged as a function of memory performance. Evidence for such link would come if the N400 to words recalled is smaller than the N400 to words forgotten. Experiments are in progress to test this hypothesis.

The long lasting LPC repetition effect here seems highly similar in latency, amplitude, and scalp distribution to the enhanced positivity associated with better memory for words. In studies explicitly designed to examine memory processes, an enhanced positivity is apparent at the initial presentation of words that will subsequently be recognized or recalled relative to those that will not (Fabiani, Karis, & Donchin, 1986; Neville et al., 1986; Paller, Kutas, & Mayes, 1987; Paller, 1990). In addition to this type difference, Neville et al. (1986) showed that correctly identified old words elicit larger positivities than correctly identified new words during the test phase. In that experiment, the words were either congruent or incongruent with a semantic context during the initial presentation, but were presented in isolation during the recognition phase. Incongruent words elicited equivalent N400s on initial presentation regardless of whether they would subsequently be recognized or forgotten. Note, however, that memory has with one exception been assessed with recognition as opposed to recall measures. Similarly, old and new words during the test phase exhibited similar N400s.

A late positivity has thus been directly linked with successful encoding and/or retrieval processes, while the N400 link is somewhat more tenuous and may vary with the nature of the memory test. In any case, the present repetition effects in the LPC latency range indicate a similarity between repetition and recognition effects. This is to be expected insofar as recognition reflects the conscious apprehension of a repeated item.

METHODS

Experiment 1

Subjects

Seventeen native speakers of English (18–34 years; 7 men) were paid for their participation. All subjects were right-handed according to self-report and the Edinburgh Inventory (Oldfield, 1971); four subjects had left-handed relatives in their immediate family. All subjects had normal or corrected-to-normal vision.

Stimuli

One hundred and sixty sentences with high (greater than 0.75) cloze probabilities (Taylor, 1953) were selected from those used by Bloom and Fischler (1979) and Kutas and Hillyard (1980). Half of these were transformed into incongruous sentences by substituting a contextually anomalous word for the original final word. These 80 incongruous words were matched in length to the 80 words used as congruous endings (5.1 versus 4.9 letters). The congruent and incongruent sentences ranged from 5 to 13 words in length (mean number of words = 8.6 for congruent, 8.0 for incongruent).

Each sentence was presented one word at a time on a CRT under the control of an Apple II microcomputer. Each word was presented for 200 msec, with a stimulus onset asynchrony between words of 500 msec. The intersentence interval was 2 sec.

Procedure

Each subject was tested in a single session lasting between 2.5 and 3 hr. Subjects were informed that they would be presented with series of semantically congruent and incongruent sentences, that they should read each sentence silently for comprehension, and that in addition they should attempt to memorize the final word of each sentence. Following the instructions, the subjects first saw a practice set of 10 sentences followed by 320 experimental sentences.

The 320 experimental sentences were presented in sets of 80, with the second two sets being repetitions of the first two. Rest periods were given after each set. Thus, the subjects first saw 160 different experimental sentences in two sets of 80. After seeing each sentence once, they were given a questionnaire with all of the experimental sentence fragments in the same order as their original occurrence and asked to fill in the missing final words; this took approximately half an hour. Immediately prior to the second presentation of the 160 sentences, subjects were told that all of the sentences would be repeated and that their task was again to remember as many of the sentence final words as possible.

Recording Techniques

The electroencephalogram (EEG) was recorded from 12 scalp sites, each referred to the left mastoid. In addition, the activity over the right mastoid was recorded, thereby allowing offline rereferencing of each scalp site to an average of the activity at the two mastoids. Nonpolarizable silver/silver chloride electrodes were placed according to the 10–20 system (Jasper, 1958) at frontal (Fz), central (Cz), parietal (Pz), and occipital (Oz) midline locations as well as laterally over anterior frontal sites (F7, F8), over left and right posterior temporal sites (30% of the interaural distance lateral to Cz, and 12.5% of the nasion–inion distance posterior to Cz), over left and right anterior temporal sites (half of the distance between F7 and T3 or F8 and T4), and over left and right temporocentral areas (33% of the interaural distance lateral to the vertex-Cz).

Vertical eye movements and blinks were monitored via an electrode on the lower orbital ridge referred to the left mastoid. Horizontal eye movements were monitored via a bipolar montage at the external canthi.

The EEG was amplified by Grass 7P122 preamplifiers with a system bandpass of 0.01 to 60 Hz (half-amplitude cutoff), and digitized online at a rate of 250 Hz by a PDP 11/45 computer. The ERPs were averaged offline for an epoch of 2048 msec, beginning 200 msec before the onset of sentence final word.

Trials with eye movements or muscle artifacts were rejected offline by a computer algorithm; these accounted for about 15% of the total trials.

Experiment 2

Subjects

Sixteen native speakers of English (9 males; 18–24 years) were paid for their participation. All but one were right-handed; five subjects had left-handed relatives in their immediate familly. All subjects had normal or corrected-to-normal vision.

Stimuli

A total of 184 sentences were selected from Bloom and Fischler (1980) and Kutas and Hillyard (1980) and coded as belonging to one of three levels of contextual constraint (58 high, 60 medium, and 66 low). For each of the 92 congruous sentences, the most probable or likely completions in a cloze procedure (Taylor, 1953) were used. The average cloze probabilities of the congruous endings were between .60 and .70 for the sentence fragments of high contextual constraint, between .40 and .50 for the sentence fragments of medium constraint, and between .20 and .30 for sentence fragments of low constraint. An equal number of sentence fragments of high, medium, and low constraint were selected to serve as the bases for the incongruous sentences. For these sentences, the expected ending was replaced by a word that rendered the sentence semantically incongruous. The words completing congruent and incongruent sentences were not significantly different in frequency of occurrence [congruent: mean = 178; incongruent: mean = 133, $F(1,91) = 2.59$]. Sentences ranged between 6 and 11 words in length with a mean of 7.9 and 8.6 for congruous and incongruous, respectively.

Procedure and Design

Subjects were tested in one session that lasted approximately 3 hr. With one exception the recording and experimental procedures were identical to those in Experiment 1. Subjects were not forewarned about the cued-recall test following the initial presentation of sentences; thus, the cued-recall following the first experimental run was incidental rather than intentional as in Experiment 1. Naturally, subjects were aware of the impending cued-recall tests following the second and third presentations of the sentences.

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