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What's in a pause: event-related potential analysis of temporal disruptions in written and spoken sentences

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Abstract

Two experiments examined the effects of disrupting the temporal patterns that develop during sentence reading and listening. Sentences were presented either visually, one word at a time (Experiment 1) or as natural speech (Experiment 2). Half of the sentences were familiar (proverbs or idioms) while the other half were constructed anew for these experiments. Within half the sentences, there was an unexpected 600-ms delay between the final two words. In both modalities, the amplitude of the N400 component of the event-related brain potential (ERP) to sentence final words was larger for unfamiliar than familiar sentences. The results in the two modalities differed, however, in that a Contingent Negative Variation (CNV) developed during the delay interval in the visual modality, whereas in the auditory modality the delay was marked by an emitted potential. The present results show that temporal patterns are processed differently in natural speech and in reading words presented one at a time in the center of a computer screen. © 1997 Elsevier Science B.V.

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1. Introduction

The following experiments were designed to assess the effects of violations of temporal expectancies during sentence processing. More specifically, we investigated the consequences of introducing an unnatural delay between the final two words of sentences on the brain's electrical activity. We start with a review of the literature on the effects of temporal violations employing both simple and complex stimuli in the auditory and visual modalities.

Early research using ERPs demonstrated that the omission of an auditory or visual stimulus in a fixed temporal sequence yields a characteristic pattern of electrical activity (Klinke et al., 1968; Ruchkin and Sutton, 1973; Ruchkin et al., 1975; Sutton et al., 1967). For example, Sutton et al. (1967) asked participants to guess for each trial whether only a single click or two clicks separated by either 180 or 500 ms would occur. All clicks were physically identical and elicited similar exogenous components. More importantly for present purposes, the results showed that a biphasic negative-positive complex (i.e. an emitted potential) was elicited in the 100- to 500-ms interval when the second click should have occurred but did not. The presence of this biphasic complex was modulated by the task instructions, as demonstrated in a second experiment wherein the clicks were not only single or double but were also either loud or soft. The emitted potential was not generated when participants' attention was oriented to the intensity of the clicks rather than to their number. These findings were of considerable interest as they were the first demonstration that some components of the ERPs (i.e. endogenous potentials) were not tied to the presentation of an actual stimulus. Sutton et al. (1967) interpreted this endogenous biphasic complex as reflecting the processing of the information provided by the stimulus. More specifically, they argued that it reflected the amount of processing necessary to reduce stimulus uncertainty; a process by which the informational content of a stimulus is extracted.

Similar results were reported by Ruchkin and Sutton (1973) in the visual modality when participants had to guess whether an upcoming stimulus would be a single or a double flash. Other studies conducted at about the same time also demonstrated that the response to a stimulus that was relevant to the participant's task was characterized by a positive component peaking around 300 ms after stimulus onset, the so-called P300 component (Donchin et al., 1973; Donchin et al., 1975; Hillyard et al., 1971; Ritter and Vaughan, 1969; Sutton et al., 1965; Sutton et al., 1967). The question naturally arose as to whether the emitted positivity reflected processes similar to those reflected by the stimulus elicited P300. While the amplitude of emitted potentials has generally been found to be smaller than that of evoked P300s (Ford et al., 1976; Ruchkin and Sutton, 1973; Ruchkin and Sutton, 1978; Sutton et al., 1967; but see Ford and Hillyard, 1981 and Ruchkin et al., 1981 for some exceptions), this finding was attributed to the presumed greater latency variability of the emitted potentials rather than to any fundamental differences between the two ERP effects. Indeed, several arguments favor the functional equivalence of the emitted and evoked P300s

(Ford et al., 1976; Ruchkin et al., 1975; Squires et al., 1975). Ruchkin et al. (1975), for instance, showed that both were influenced similarly by factors such as the probability of stimulus occurrence; the amplitudes of the emitted and evoked P300s alike are inversely correlated with stimulus probability. Simson et al. (1977) further showed that the P300s elicited by infrequent stimuli in the auditory and visual modalities as well as by omitted events (Simson et al., 1976), all had a centro-parietal maximum. Thus, the consensus to date is that the evoked and emitted P300 are one and the same physiological process, reflecting the same cognitive operations (Simson et al., 1977; Sutton et al., 1967). While results of numerous experiments reveal that the P300 component is sensitive to a number of factors, Johnson (1986) has proposed that the three main factors that will account for the variations in P300 amplitude are subjective probability, stimulus meaning and information transmission.

Stimuli more complex than regular click sequences have recently been used to investigate rhythmic violations within musical phrases (Besson and Faita, 1995; Besson et al., 1994). Specifically, we asked musicians and non-musicians to listen to familiar, well-known musical phrases from the classical repertoire and to unfamiliar melodies, composed expressly for the experiment. Both familiar and unfamiliar melodies terminated with the expected, congruous notes on half of the trials. But on the other half of the trials, the final notes were unexpected nondiatonic changes (i.e. notes out of key), diatonic changes (i.e. notes within the key but not the most expected according to melodic contour) or rhythmic changes. Of greatest interest for present purposes, in the rhythmic violation condition the final note was delayed by 600 ms. This delay was clearly noticeable since the average interval between the previous notes was typically between 50 and 400 ms depending upon the particular musical piece. In one experiment, participants completed a questionnaire to indicate to which of the four categories (congruous, nondiatonic, diatonic and rhythmic) they thought the last note belonged. The results showed that rhythmic incongruities were easily and equivalently detected by musicians and non-musicians alike regardless of the piece's familiarity. This was expected insofar as no musical knowledge should be necessary to detect a 600-ms delay between the final two notes. In two subsequent experiments, ERPs were also recorded. In both experiments, late positive components, probably of the P300 family, were associated with the nondiatonic and diatonic changes; these were, overall, larger for musicians than for non-musicians and for familiar than unfamiliar melodies. Furthermore, in both experiments, large emitted potentials were elicited at the time when the final note should have occurred — in other words to the absence of the final note, and an N1-P2 complex was elicited by the final note when it actually did occur. Note that neither the nature nor the timing of the emitted potentials differed between musicians and non-musicians, although they were larger in amplitude for familiar than unfamiliar melodies. Therefore, it may be that higher order processes, such as temporal expectations for an event based on a priori knowledge of the musical piece, influenced the amplitude of the emitted potential. The amplitude of emitted potentials thus can be modulated both by instructions (larger when participants pay attention to the temporal aspects of the sound's sequence than when they discriminate loud from soft sounds, Sutton et al., 1967) and by prior knowledge of the materials (familiar vs. unfamiliar melodies, Besson and Faita, 1995).

However, music is not the only organized system that is composed of sequential events that extend in time. Indeed, natural languages share this same characteristic. It is therefore reasonable to assume that temporal information might play a crucial role in both. The primary aim of the present experiments was to see whether an effect similar to that obtained with musical phrases would obtain with linguistic materials as well. Specifically, we aimed to determine whether the disruption of temporal patterning in music and language would yield equivalent ERP effects. Insofar as the ERPs elicited in music and language were similar we would argue for a domain-general process dealing with temporal information in both domains. We investigated whether emitted potentials could be elicited by disrupting temporal structure during both written and spoken language processing.

Isolated sentences were presented either visually, at a rate of one word every 500 ms (Experiment 1) or as natural speech (Experiment 2); in both cases a 600-ms delay was introduced between the penultimate and final words of half the sentences. Moreover, in order to assess the effects of familiarity observed with musical materials, the sentences were either well-known proverbs and idioms (i.e. familiar), or new sentences (i.e. unfamiliar) generated expressly for these experiments. Consequently, the familiar and unfamiliar sentence endings differed in their cloze probability (that is, the probability that a specific word will be given as completion for a specific sentence context, Taylor, 1953), being high for the familiar proverbs and low for the unfamiliar sentences. Results of numerous experiments have shown that the amplitude of the N400 component of the ERP (Kutas and Hillyard, 1980), is inversely proportional to the cloze probability of the sentence's terminal word (Kutas and Hillyard, 1984; Kutas et al., 1984). Thus, we expected the N400 elicited by the sentence terminal words in the No-Delay condition to be larger for unfamiliar than familiar sentences. Of greater interest, however, was to observe whether emitted potentials would be elicited in the Delay condition and if so, whether its amplitude would vary as a function of the familiarity of the sentences.

2. Experiment 1

The Rapid Serial Visual Presentation (RSVP) procedure has been widely used in ERPs and language experiments to study the influence of different factors on linguistic processing (Besson et al., 1992; Fischler and Raney, 1991; Hagoort et al., 1993; Karayanidis et al., 1991; King and Kutas, 1995; Kutas and Hillyard, 1980; Kutas and Hillyard, 1984; Neville et al., 1986; Osterhout and Holcomb, 1992; Van Petten and Kutas, 1987; Van Petten et al., 1991). In experiments like these, sentences are presented one word at a time in the center of a computer screen. Participants are asked to read the sentence silently for meaning and, in some cases, to try to remember the final word of each sentence. Insofar as the rate of word presentation is constant, with a stimulus onset asynchrony (SOA) usually between 100 and 1000 ms, participants come to expect, not necessarily consciously, each word to be presented at a specific time. It is thus possible to examine the effects of a temporal disruption in the rate of word presentation. Based on previous reports that an emitted potential is elicited when a stimulus is expected but not presented, we hypothesized that an emitted potential would be elicited at the moment when the last word of the sentence should have been presented but was not presented due to a 600-ms delay.

2.1. Method

2.1.1. Participants

Nine native French speakers[1] (age range, 18–27, mean = 22.8 years; 5 women) were paid for their participation in one 2.5-h session. All participants were right-handed according to self-report and none had left-handed relatives in their immediate family. All participants had normal or corrected-to-normal vision.

2.1.2. Materials

Two-hundred sentences were presented in this experiment (see sample sentences in Appendix A). One-hundred sentences were chosen from a pool of 576 sentences for which completion norms have been compiled (Robichon et al., 1996). The final words of these sentences had low cloze probabilities ($P < 0.33$, *e.g. "Je l'ai souvent rencontre dans ce parc.", "I have often met him in this park.",)* and have been shown to elicit large N400s (Besson and Kutas, 1993). The remaining 100 sentences were selected from a pool of 110 proverbs *(e.g. "Tout ce qui brille n'est point or.", "All that glitters is not gold.")* for which completion norms also have been compiled (Robichon et al., 1996). For proverbs, the terminal word's cloze probability was higher than 0.75. Sentences ranged from five to eleven words in length (six words on average).

2.1.3. Procedure and design

Following electrode application, each participant was comfortably seated in an electrically-shielded room. Sentences were presented one word at a time in the center of a CRT screen situated 60 cm in front of the participant. Each word was written in lowercase and presented for 200 ms with a 500-ms SOA. Half of the sentences were presented in the No-Delay condition and the other half in the Delay condition. In the Delay condition the presentation of the terminal word was delayed by an additional 600 ms such that the SOA between the penultimate and the sentence final word was 1100 ms. The inter-sentence interval was 2 s. The experiment was under the control of an Olivetti M240 personal computer.

[1] In both experiments, participants were native French speakers. However, while Experiment 1 was conducted in the Center for Research in Cognitive Neuroscience in Marseille, Experiment 2 was conducted in the Cognitive Electrophysiology Laboratory of the Cognitive Science Department in San Diego.

Each session comprised three blocks of 72, 72 and 56 trials, respectively. Within each block an equal number of low cloze probability sentences and proverbs, and of delayed and not-delayed terminal words, were pseudo-randomly intermixed with the constraint that no more than three sentences from the same category occurred successively.

To control for item variance, two different lists of 200 sentences were constructed so that across lists each sentence occurred either in the No-Delay or in the Delay condition. Each list was presented to a different group of participants. No participant saw the same sentence frame in more than one condition. Three different orders of presentation were used for each list and participants were randomly assigned to one of the two lists and one of the three orders.

At the beginning of the session, participants were informed that they would be presented with several series of sentences which they were to read silently for comprehension. They were told that while some sentences were new, some were familiar (proverbs), but that all sentences should be treated equally. Participants also were asked to avoid blinking throughout each sentence until a row of XXXX appeared on the screen, 2 s after final word onset; they were trained to blink during the inter-sentence interval. Following the instructions, the participants saw a practice set of 10 sentences followed by the first block of sentences.

2.1.4. Recordings

EEG was recorded via Ag/AgCl electrodes from seven scalp sites: three along the midline at Fz, Cz and Pz and two lateral pairs over temporo-anterior (10% of the interaural distance lateral to Cz and 20% of the distance between this point and FPz on the left and on the right) and temporo-posterior regions (30% of the interaural distance lateral to Cz and 12.5% of the inion-nasion distance posterior to Cz, on the left and on the right), each referred to the left mastoid. Eye movements and blinks were monitored via an electrode on the lower orbital ridge referred to the left mastoid. Electrode impedances never exceeded 3 kOhms.

The EEG was amplified by Grass P5 RPS107 amplifiers with a bandpass of 0.01–30 Hz (half-amplitude cutoff). The sampling rate was 250 Hz. Approximately 10% of the trials were contaminated with eye movements or muscle artifacts; these were rejected off-line based both on computer algorithms using individually adjusted thresholds, and visual inspection.

2.1.5. Data analysis

ERPs for each condition for each participant were averaged off-line for a 2200-ms epoch. In the No-Delay condition, recording was time-locked to the onset of the sentence terminal word. In the Delay condition, the recording was time-locked to the moment when the terminal word should have occurred naturally. Thus, the durations of the recording epochs were equivalent in the two conditions. The ERP data analyses were based on the mean amplitude in selected latency windows relative to a 200-ms baseline computed before the sentence final word was (No-Delay condition) or should have been (Delay condition) presented. To be consistent with previous literature, the N400 was measured between 300–600 ms.

Repeated measures analyses of variance (ANOVAs) were carried out with the Greenhouse-Geisser correction for inhomogeneity of variance applied where appropriate; reported are the uncorrected degrees of freedom, the epsilon value, and probability level following correction. Unless otherwise specified, Tukey (HSD) tests were used to test the significance of post-hoc comparisons.

2.2. Results

The difference in the timing of stimulus presentation in the No-Delay and Delay conditions yielded very different ERP patterns (Fig. 1). Thus, it did not seem appropriate to compare results in the two conditions by taking measures in the

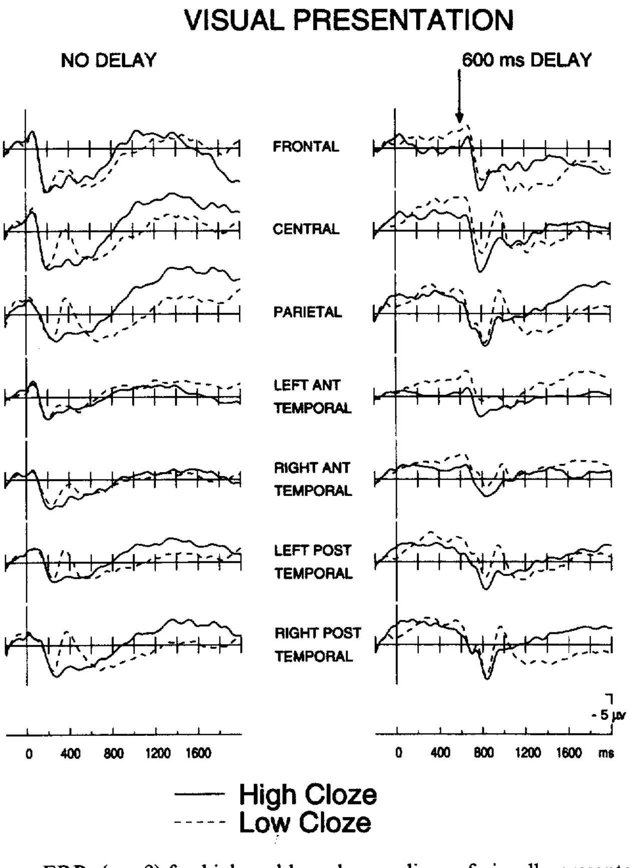

Fig. 1. Grand average ERPs ($n = 9$) for high and low cloze endings of visually presented sentences in the No-Delay (left column) and Delay conditions (right column). For delayed endings, the arrow points to the moment when the final word was presented. Number of trials contributing to the averages (n): for high cloze endings, No-Delay, $n = 398$ and Delay, $n = 402$; for low cloze endings, No-Delay, $n = 401$ and Delay, $n = 407$. In this and the following figure, traces corresponding to each recording site are presented and negative is up.

same latency windows. Rather, latency ranges for data analyses were based on previous results and from visual inspection of the ERP traces in the two conditions. Similarly, including Delay versus No-Delay as a factor in the ANOVA is of no added benefit as the main effect of this factor is obviously significant. Thus, we report analyses for each condition separately.

2.2.1. *ERPs to the non-delayed endings*

Large N400 components with the typical centro-parietal maximum, and slight right hemisphere preponderance, were elicited by congruent but low cloze probability terminal words while virtually no N400 was elicited by terminal words of the proverbs (see left column of Fig. 1). Following the N400, a negative slow wave (NSW) developed from 600 ms to the end of the recording epoch. This NSW appeared larger for high than low cloze endings.

A two-way ANOVA, including the terminal word's cloze probability (low vs. high) and electrode (seven levels) as factors, revealed significant main effects of both between 300–600 ms post-terminal word onset (cloze probability: $F(1,8) = 20.74$, $\mathrm{MSe} = 4.34$, $P < 0.001$ and electrodes: $F(6,48) = 6.76$, $\mathrm{MSe} = 2.40$, epsilon $= 0.36$, $P < 0.006$). The mean amplitude of the potential was less positive for low (1.20 μV) than high (2.89 μV) cloze probability endings. Results of post-hoc comparisons (Tukey HSD) showed that the mean amplitude was significantly less positive over parietal and temporo-posterior sites (Pz = 1.42 μV, LPT = 1.16 μV and RPT = 1.62 μV) than over fronto-anterior sites (Fz = 3.84 μV, LAT = 1.48 μV, RAT = 2.04 μV, Cz = 2.77 μV). The difference between left and right sites was not significant ($F(1,8) = 2.79$, $\mathrm{MSe} = 1.68$, $P = 0.13$).

Analysis of the negative slow wave (NSW), in the 600- to 1200-ms latency range, showed that the main effect of cloze probability and the cloze probability by electrode interaction were significant ($F(1,8) = 4.84$, $\mathrm{MSe} = 4.64$, $P < 0.05$ and $F(6,48) = 3.10$, $\mathrm{MSe} = 5.14$, epsilon $= 0.53$, $P < 0.04$). Results of post-hoc Tukey (HSD) tests showed that the NSW was larger for high than low cloze probability words over centro-parietal and temporo-posterior locations.

2.2.2. *ERPs to the delayed endings*

As can be seen in the right column of Fig. 1, a slow negative shift, the CNV (Walter et al., 1964) developed in the 600-ms interval between the last two words of the sentence. The CNV appears to be larger for terminal words with low than high cloze probability, at least at temporo-anterior and central sites. An N1-P2 complex was then elicited by the sentence final word. Following the N1-P2, an N400 component was associated with low cloze endings, but was virtually absent from the ERPs to high cloze endings. An NSW was also present at parietal and temporo-posterior locations; it was larger for high than low cloze endings.

Two-way ANOVAs with the same factors as above, were performed in successive latency bands. Results showed that the CNV was significantly larger for low (-2.49 μV) than high (-1.52 μV) cloze probability endings in the 200- to 600-ms range ($F(1,8) = 5.16$, $\mathrm{MSe} = 3.22$, $P < 0.05$). The mean amplitude of the CNV was larger at temporo-posterior (-2.58 μV) than temporo-anterior locations (-1.43 μV; $F(1,8) = 7.96$, $\mathrm{MSe} = 3.01$, $P < 0.02$).

The difference between high and low cloze probability endings was also significant between 0 and 150 ms of the actual terminal word onset (600- to 750-ms latency band): that is, the mean amplitude in this window was more negative for low (-2.61 μV) than high (-1.02 μV) cloze endings ($F(1,8) = 10.04$, MSe = 7.93, $P < 0.01$). Neither the main effect of electrode location nor the cloze probability by electrodes interaction was significant.

Cloze probability failed to significantly alter the P2 component, measured between 150 and 350 ms post-terminal word onset.

The amplitude of the N400, measured between 350 and 450 ms post-terminal word onset[2] (950–1050 ms range) was larger for low (-0.94 μV) than high (1.34 μV) cloze endings ($F(1,8) = 5.52$, MSe = 30.08, $P < 0.04$). Neither the main effect of electrode location nor the cloze probability by electrode interaction was significant.

Finally, the NSW measured between 450 and 1000 ms post-terminal word onset (1050–1600 ms), was larger for high than low cloze endings at right temporo-posterior and parietal locations (cloze probability by electrode interaction: $F(6,48) = 5.51$, MSe = 5.27, $P < 0.01$).

2.3. Discussion

Our results clearly show the development of a CNV in the 600-ms interval between the last two words of these visually presented sentences. These findings are consistent with previous results using an RSVP procedure, showing that a CNV develops between words and across the course of sentences (Kutas and Hillyard, 1980; 1984; Kutas et al., 1988; Van Petten et al., 1991). The finding that no emitted potential is generated when the final word should have been presented is, however, in marked contrast with previous results obtained with musical phrases (Besson and Faita, 1995). When a 600-ms delay was introduced between the last two notes of musical phrases, the absence of the final note at the expected moment was marked by an emitted potential.

At least two different interpretations can be offered to account for this discrepancy. On the one hand, it may be that fundamentally different cognitive operations are called into play in response to temporal disruptions within linguistic and musical contexts. In fact, several authors have emphasized the differences rather than the similarities between language and music processing (Kivy, 1990; Clarke, 1989). Specifically, the relative importance of temporal information may differ within the two systems. Rhythm is an intrinsic property of music and several experiments have demonstrated that music perception is very dependent upon its rhythmic structure (Jones, 1981; Longuet-Higgins and Lee, 1984; Peretz and Kolinsky, 1993; Sternberg et al., 1982). For instance, Sternberg et al. (1982) showed that highly trained musicians were unable to correctly judge the duration of

[2] The N400 was measured in this latency band rather than in the usual 300- to 600-ms range because, as can be seen from the traces, the effect of cloze probability had a shorter duration for delayed than not-delayed endings. Analysis in the 300- to 600-ms latency band post-delayed word onset (900–1200 ms range) showed that the main effect of cloze probability was not significant.

temporal intervals within a musical sequence (the 'bar') when the beats were irregularly spaced. Our previous music results are consistent with a model of music perception based on expectancy (Jones, 1981, 1982), defined as a 'time-based analog response to specific pattern regularities' (Jones, 1981; p. 37). The temporal dimension thus plays a central role in this model and, as noted by Jones (1981; p. 38), 'An event that occurs too early or too late violates one's expectancy just as much as does the timely occurrence of the wrong event'. The occurrence of a large emitted potential in response to the absence of the note, when the event occurs 'too late', clearly demonstrates that the rhythmic violation was inconsistent with the musical expectancy. Furthermore, the emitted potential was, in some respects, similar to the ERP effect observed in response to the presentation of 'wrong' terminal notes, such as nondiatonic and diatonic incongruities (for a discussion of these matters, see Besson and Faita, 1995; Besson, in press). Thus, it may be that temporal structure exerts a greater influence in music than in language perception. In the case of music, a specific event (note or chord) is expected to occur at a specific time and its rhythmic structure influences how the auditory signal is perceived as music. By contrast, in the case of language, the regular, stable temporal structure of the RSVP procedure does not add much information to the actual comprehension process; the meaning of written words is, at least in our experiment, independent of timing. The main consequence of delaying the terminal word is thus merely to postpone the comprehension process that allows the formation of a meaningful, coherent representation of the sentence. It does not, however, change the propositional content of any sentence.

On the other hand, one might argue that the temporal dimension does play an important role in language processing, just as in music perception but only for spoken language. As in musical phrases, the linguistic signal in speech unfolds continuously across time. Thus, it may be that the differences found in the processing of temporal disruptions within language and music do not reflect fundamental differences between the two, but rather emerge from the different modes of stimulus presentation (auditory vs. visual) used in the experiments. Furthermore, while the rhythmic structure of the musical phrases was respected except for the violations, the RSVP procedure used in the present experiment did not respect the temporal aspects of natural reading. There is, for instance, considerable variability in reading rates which are, furthermore, generally not constant from word to word. Consequently, either the mode of stimulus presentation (auditory vs. visual), or the relative importance of and respect for temporal structure may explain the differences found between the music and reading experiments. Experiment 2 was designed to explore these interpretations further.

The results of Experiment 1 replicate reports that N400 amplitude is modulated by cloze probability; it was larger for low than high cloze probability endings. Note that high cloze probability words were terminal words of proverbs or idioms. While such materials have been included in previous experiments (Besson and Macar, 1987; Kutas and Hillyard, 1980), to our knowledge idioms were not analyzed separately from other high cloze probability words of less idiomatic congruent sentences. Our results thus extend the range of the cloze probability effects to show that when the terminal word can be predicted precisely, the N400 is virtually absent. This result is in line with the hypothesis that the N400 is a good index of semantic expectancy (Kutas and Hillyard, 1984).

One final point deserves comment. Early ERP work demonstrated that the CNV developed during the interval between two stimuli, or events, whenever the first signalled that the second, relevant for the participant, would occur (Walter et al., 1964). The CNV has been interpreted among other proposals as reflecting expectancy and/or preparatory processes (Rebert and Tecce, 1973; Walter et al., 1964) and time estimation (Macar and Vitton, 1979). More recent work by Ruchkin et al. (1986), among others, clearly demonstrates that the CNV can be obtained in the absence of motor response. Furthermore, using two stimuli separated by 1-s or 3-s intervals, they showed that the amplitude of the CNV was larger when the occurrence of the second one reduced uncertainty than when it did not. Thus, our finding that a CNV developed in the 600-ms interval between the final two words of the sentence, when no motor response was required, is in line with such results, thereby relating the CNV more to expectancy for the final word.

The amplitude of the CNV was reliably larger for unfamiliar than familiar (proverbs) sentences. This finding can easily be explained by an expectancy-based view of CNV generation such as described above. In the high cloze (proverbs) condition, insofar as participants recognized the proverbs or idioms, they could predict the endings such that they knew which word would occur before it was actually presented. In contrast, in the low cloze probability condition, the terminal word could not be predicted accurately and the uncertainty was greater. Therefore, resolution of expectancy may have occurred earlier for proverbs than for unfamiliar sentences and this may explain the finding of a larger CNV in this latter condition. Since the emitted potential to the absence of the note in music experiments was shown to be larger for familiar than unfamiliar melodies, the finding of a larger CNV to unfamiliar than familiar sentences again points to a possible difference between language and music processing. This point will be considered further in the general discussion.

The mean amplitude in what is usually considered the N1 region of the ERP, namely between 0 and 150 ms, was significantly more negative for low than high cloze probability endings. Although one might want to argue that this is just an N1 effect (Hillyard et al., 1973; Mangun et al., 1993; Woldorff and Hillyard, 1991), we believe this not to be the case. As can be seen in Fig. 1, over fronto-central sites, the effect appears to start over 150 ms prior to the N1 per se. Moreover, a peak-to-peak analysis indicated that N1-P2 amplitudes were equivalent in the high and low cloze conditions, consistent with our argument that the apparently larger N1 in the low cloze condition was due to its riding on a large pre-stimulus CNV.

Finally, it could be argued that what we consider to be an N400 effect in the delay condition reflects the resolution of the CNV instead. There are at least two reasons why this is not likely to be the case. First, when the ERPs from the high and low cloze delay conditions closely overlap, as can be seen at parietal and right temporo-posterior locations for instance, the N400 is nevertheless larger for low than high cloze endings. There is no clear reason why the resolution of the CNV should show such a localized differential effect in these two conditions. Second, the N400 effects in the delay and no-delay conditions are remarkably similar. In this last condition, however, no CNV was generated prior to the N400.

3. Experiment 2

The data of Experiment 1 showed that, in contrast to the results obtained in music experiments, a CNV developed in the 600-ms interval between the last two words of the sentences. We offered two hypotheses to account for this difference due either to intrinsic differences between language and music, or to the mode of stimulus presentation used. To test these alternative interpretations, we conducted a similar experiment using natural, continuous speech with the very same sentences. Sentences were spoken at a normal speech rate, recorded and digitized, and then presented under computer control. If the differences found in the ERPs to temporal disruptions within RSVP reading and music reflected differences between language and music processing, we would expect to obtain a similar pattern of differences with speech. That is, we expect a CNV to develop in the 600-ms interval between the last two words of the spoken sentences. If, on the other hand, these differences are linked to the mode of stimulus presentation, namely visual versus auditory, or to the unnatural, relatively slow RSVP procedure, the ERPs should resemble those recorded in the music experiments; in other words, we would expect to see an emitted potential in response to a temporally delayed final word in spoken sentences.

3.1. Method

3.1.1. Participants

Nine native French speakers[1] (age range, 21–34, mean = 29.0 years; five women), were paid for their participation in a 2.5-h session. All participants but one were right-handed according to self-report and none had left-handed relatives in their immediate family. All participants had normal hearing. One participant had to be discarded from the final analysis because too many of the trials (over 40%) were contaminated by eye-movements and muscle artifacts.

3.1.2. Materials

The same 200 sentences as in Experiment 1 were presented; however, in this experiment, they were spoken. One of the experimenters read the sentences at normal rate; these were recorded and digitized at a sampling rate of 44 100 Hz (16 Bit Mono) using the Wave software for PC. The sound sequence for each sentence was displayed on the computer screen and the onset of each terminal word was marked by a digital code. For each sentence, EEG recordings were time-locked to the onset of the terminal words. The duration of the recording period (2200 ms) was identical for all sentences in all the experimental conditions. In the Delay condition, a 600-ms delay was introduced between the last two words of each sentence.

3.1.3. Procedure and design

Following electrode application, each participant was comfortably seated in an electrically-shielded sound-attenuated chamber. Sentences were presented through two loudspeakers (BOSE) located approximately 30 degrees laterally in front of the participants. Each sentence was played at a comfortable intensity level. Half of the terminal words had high cloze and the other half low cloze probabilities, and half of the sentences were presented in the No-Delay condition and the other half in the Delay condition. The inter-sentence interval was 2 s.

The procedures were in all respects identical to those in Experiment 1.

3.1.4. Recordings

Except for the fact that EEG was recorded via an ElectroCap (tin), rather than from separate Ag/AgCl cup electrodes, recordings and data analyses were identical to those in Experiment 1.

3.2. Results

3.2.1. ERPs to the non-delayed endings

As can be seen in the left column of Fig. 2, low cloze probability endings in the No-Delay condition were associated with a large negative component between 100 and 600 ms; the negativity was largest over centro-parietal sites and seemed to be slightly larger over the right than the left hemisphere. These were followed by a positivity over parietal and right temporo-posterior sites that lasted from 600 ms to the end of the recording epoch. By contrast, the high cloze endings were not associated with a negative component but rather with a positive shift.

In a two-way ANOVA, with cloze probability (low vs. high) and electrode (seven levels) as factors, both the main effect of cloze probability and its interaction with electrodes were significant between 100–600 ms ($F(1,7) = 5.60$, MSe = 7.92, $P < 0.04$ and $F(6,42) = 3.87$, MSe = 1.08, epsilon = 0.35, $P < 0.04$, respectively). The negativity was larger for low (-2.04 μV) than high cloze endings (-0.78 μV). To allow a direct comparison with the results of Experiment 1, this analysis was also conducted for a mean amplitude 300–600 ms measure. Results were similar to those for the 100- to 600-ms epoch, except that the cloze probability by electrode interaction was no longer significant (main effect of cloze probability: $F(1,7) = 5.37$, MSe = 17.11, $P < 0.05$; cloze probability by electrodes interaction: $F(6,42) = 3.15$, MSe = 1.27, epsilon = 0.34, $P = 0.07$).

Between 600 and 1800 ms there was no main effect of cloze probability ($F < 1$) but there was a significant interaction between cloze probability and electrodes ($F(6,42) = 3.27$, MSe = 0.89, epsilon = 0.58, $P < 0.02$). This interaction reflected the fact that over temporo-posterior sites, the late positivity was larger for low (1.85 μV) than high cloze endings (0.95 μV), but that this pattern was reversed over temporo-anterior sites (low = 1.01 μV and high = 1.44 μV; $F(1,7) = 12.25$, MSe = 0.57, $P < 0.01$). Furthermore, the difference between high and low cloze endings was larger over the left than right hemisphere (cloze probability by anterior/posterior by hemisphere: $F(1,7) = 7.62$, MSe = 0.19, $P < 0.02$).

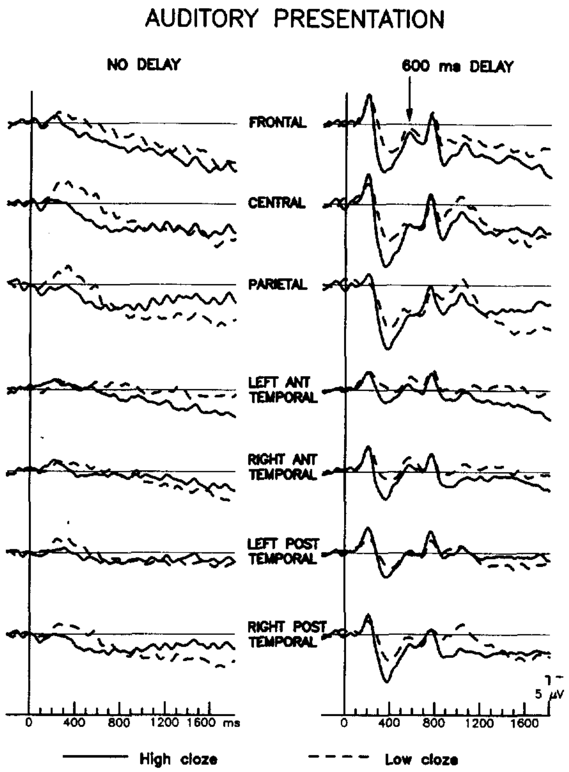

Fig. 2. Grand average ERPs ($n = 8$) for high and low cloze endings of spoken sentences in the No-Delay (left column) and Delay conditions (right column). For delayed endings, the arrow points to the moment when the final word was presented. Number of trials contributing to the averages (n): for high cloze endings, No-Delay, $n = 388$ and Delay, $n = 397$; for low cloze endings, No-Delay, $n = 380$ and Delay, $n = 391$.

3.2.2. ERPs to the delayed endings

As shown in the right column of Fig. 2, a large emitted potential is elicited in the Delay condition, at the moment the terminal word should have been presented. This emitted potential comprises a negative component peaking at 200 ms followed by a positive component peaking between 350–400 ms. Following the emitted potential, we see the N1-P2 complex to the delayed terminal words, followed by an N400 component, that is larger for low than high cloze endings. Late positivities then develop at centro-parietal sites and last until the end of the recording epoch.

While the negative component of the emitted potential, peaking around 200 ms, appears slightly larger for high than low cloze endings at fronto-central locations this difference was not reliable (100–200 ms range: $F < 1$). Analysis of the mean amplitude between 200–500 ms revealed that the positive component of the emitted potential was significantly larger for high (2.57 μV) than low (1.22 μV) cloze probability endings ($F(1,7) = 5.05$, MSe $= 10.09$, $P < 0.05$) and did not interact significantly with electrode locations ($F(6,42) = 1.30$, MSe $= 0.83$, $P = 0.30$).

Analysis within the 300- to 600-ms window post-terminal word onset (900–1200 ms) showed a significant N400 effect with larger N400s for low (-0.06 μV) than high cloze probability endings (1.90 μV; $F(1,7) = 8.78$, MSe $= 12.38$, $P < 0.02$). The N400 effect was larger over the right (2.27 μV) than left hemisphere (-0.62 μV; ($F(1,7) = 5.81$, MSe $= 1.88$, $P < 0.04$).

Between 600–1200 ms following the onset of the terminal word (1200–1800 ms), the cloze probability by electrode interaction was significant ($F(6,42) = 4.62$, MSe $= 1.66$, $P < 0.01$). This reflected the fact that while at temporo-anterior locations, larger late positive shifts were associated with high (1.95 μV) than low cloze endings (1.45 μV), at temporo-posterior locations, larger positive shifts were elicited by low (1.85 μV) than high cloze endings (0.31 μV; ($F(1,7) = 12.47$, MSe $= 1.33$, $P < 0.009$).

3.3. Discussion

In contrast to the pattern of effects reported in Experiment 1, the results of Experiment 2 clearly showed that an emitted potential was elicited at the moment the sentence final word should have occurred. Before discussing the possible reasons why different patterns of results were found in Experiments 1 and 2 (see Section 4), and the relationship to results found in previous music experiments, we first consider the specific findings of Experiment 2.

In line with previous findings, ERPs in the No-Delay condition showed an auditory N400 effect with larger N400 components to low than high cloze endings. Note that the N400 effect is clearly not as peaked and temporally localized in the auditory as in the visual modality. This finding is typical of auditory presentation when words of different duration are presented and the auditory signal extends in time. Words are consequently recognized at different times and N400's peak latency varies from one word to the other (Bentin et al., 1993; Holcomb and Neville, 1990; 1991; McCallum et al., 1984). Furthermore, the auditory N400 effect was significant in the 100- to 600-ms latency band, thus showing an earlier onset than in the visual modality, where the differences between high and low cloze endings started around 300 ms. Similarly, between modality latency differences were reported by Holcomb and Neville (1990) in an experiment using related and unrelated word pairs. Larger N400s were elicited by target words unrelated to the primes than by related target words in both modalities, albeit with an earlier onset for the spoken word pairs. In contrast to these and our findings, McCallum et al. (1984) did not report an earlier onset of the N400 effect for spoken sentences. They did not, however, use natural connected speech but rather spliced endings from one sentence into another. Therefore, as noted by Holcomb and Neville (1991), this manipulation of the speech signal may have altered non-semantic cues, such as prosody or coarticulation, that would normally influence speech comprehension. The absence of natural speech cues may have slowed down sentence comprehension and thereby delayed the N400 effect. This hypothesis was later tested and supported by the results of Holcomb and Neville (1991).

Interestingly, while the reasons that motivated the present experiments differ from those of Holcomb and Neville (1991), very similar results were found in both. Our results in the Delay condition also showed an N400 effect that onset later, around 250 ms, than in the No-Delay condition (onset around 100 ms). While it may be, as proposed by Holcomb and Neville (1991), that the longer latency of the N400 effect in the delayed condition reflects the fact that prosodic or coarticulation cues could not be used when the final spoken words were artificially delayed by 600 ms, a different interpretation can account for these data as well. The comprehension processes reflected in the N400 effect may be delayed simply because participants are surprised not to hear a word when they are expecting it. The surprise effect would delay comprehension. It will thus be important in future experiments to determine whether the results reported here and in Holcomb and Neville (1991) reflect the influence of prosodic or coarticulation cues or less specific surprise effects.

Two other findings deserve comment. First, the amplitude of the N1-P2 complex associated with the presentation of the final words was larger in the Delay than No-Delay conditions. Similar results have been reported in several experiments and have been interpreted as reflecting the physiological refractory period of the early sensory ERPs components for fast rates of stimulus presentation (Besson and Faita, 1995; Gastaut et al., 1951; Knight et al., 1980; Holcomb and Neville, 1991). Second, the amplitude of the emitted potentials was larger for familiar than unfamiliar sentences. This is in line with results from the music experiments showing larger emitted potentials to rhythmic incongruity within familiar than unfamiliar melodies. These results are important in that they demonstrate that the amplitude of the emitted potential is modulated by cognitive factors such as knowledge of which word or note should be presented and when this event should occur.

4. General discussion

The main aim of the present experiments was to study the effects of temporal disruptions in written and spoken sentences in order to compare results with previous ones obtained with musical phrases. Very different patterns of results were found in Experiments 1 and 2. While a CNV developed in the 600-ms interval between the final two words of written sentences, an emitted potential was elicited in spoken sentences. This last result is very similar to that observed when a 600-ms interval was introduced between the final two notes of musical phrases. Therefore, while the results of Experiment 1 could have led to the conclusion that different processes underlie the processing of temporal disruptions in language and music, results of Experiment 2 clearly contradict this conclusion. Emitted potentials were elicited by temporal disruptions in both spoken and musical phrases. These results thus argue for a domain-general process dealing with temporal information in both language and music systems.

Why did a CNV develop in the interval between the final two words of written, but not spoken, sentences? One could argue that while CNVs are elicited by temporal delays in the visual modality, emitted potentials are elicited in the auditory modality. Such an explanation is unlikely for two reasons. First, as mentioned in the introduction, emitted potentials have been elicited in the visual modality when simple stimuli, such as flashes were omitted from a regular sequence (Ruchkin and Sutton, 1973; Simson et al., 1976). Second, there were important differences other than modality between Experiments 1 and 2. In particular, sentences in Experiment 2 were spoken normally thereby respecting the constraints of natural language (Pisoni and Luce, 1987), in the same way that the rhythmic structure of the musical phrases was respected in previous music experiments (Besson and Faita, 1995; Besson et al., 1994). In contrast, sentences in Experiment 1, were presented using an unnatural RSVP procedure, thereby differing from normal reading from the outset. Words were presented on the computer screen for an equal duration and at a fixed regular rate, independent of their length, frequency of occurrence in the language and other factors that would normally influence an individual's reading rate. Therefore, the main difference between Experiments 1 and 2 most likely is the greater salience of temporal disruptions in continuous speech than in an RSVP reading. From the point of view of a reader, the 600-ms interval in the Delay condition may represent only a slight lengthening of an already unnatural delay between words (ISI was 300 ms, with a 500-ms SOA in the No-Delay condition). These results, thus, clearly demonstrate that different brain electrophysiological responses are obtained with different modes of stimulus presentation.

Why did results show larger CNVs for low than high cloze endings in the visual modality, while they reveal larger emitted potentials for high than low cloze endings in Experiment 2? In other words, why did we find a reverse familiarity effect in the two experiments? On empirical and common-sense grounds, it seems clear that the stronger the expectation, the stronger the surprise effect when the expectations are not fulfilled. Based on this assumption one would predict larger effects of temporal disruptions for familiar than unfamiliar materials, and this is indeed what we found for spoken sentences. The emitted potential to temporal disruptions was larger for familiar (proverbs) than unfamiliar sentences as was also the case for musical phrases. However this is not what we found for visual presentation. As mentioned previously, because we used a rather slow RSVP procedure in Experiment 1, it is likely that participants had sufficient time to anticipate and process the final words of the familiar proverbs before they were actually presented. Anticipation of the actual final word was consequently not as strong in this case as when the endings were not as predictable (i.e. low cloze). In other words, while presenting the final words reduced uncertainty in the case of low cloze endings, it did not in the case of high cloze probability words. Again, these results are in line with those reported by Ruchkin et al. (1986) showing larger CNV when the upcoming stimulus reduces uncertainty than when it does not.

The results presented here have interesting implications for future research. The finding that the brain's response was very sensitive to the disruption of temporal structure in spoken sentences provides a new avenue for studying factors such as rhythm and prosody, that have been shown to influence language comprehension

(Cuttler, 1987; 1989; Ross, 1981), but have not yet, to our knowledge, been studied using a measure of brain activity such as ERPs. Note, for instance, that pauses have specific roles in language production. This is clearly illustrated by the analysis of political discourse (Duez, 1995). In such cases, pauses are very well controlled for and have different functions depending upon the aim of the politician: they may allow better comprehension, time for approval, or attract attention. Furthermore, the number and duration of pauses, as well as rate of speech, are important within public speaking (Duez, 1995). The emitted potential thus provides an interesting tool for studying the role of pauses, and more generally of the prosodic contour, in spoken language.

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Appendix A

A.1. High cloze probability endings (proverbs and idioms)

Il n'y a que la verite qui fache.
Le soleil brille pour tout le monde.
Les petits ruisseaux font les grandes rivieres.
A coeur vaillant rien d'impossible.
Aux innocents les mains pleines.
L'arbre cache la foret.
Loin des yeux loin du coeur.
L'appetit vient en mangeant.
Chacun pour soi et Dieu pour tous.
Qui se ressemble s'assemble.
L'occasion fait le larron.
Au royaume des aveugles les borgnes sont rois.
Tout nouveau tout beau.
Pas de nouvelles bonne nouvelle.
Mieux vaut tard que jamais.

A.2. Low cloze probability endings

Hier il a achete du pain de campagne.
Il dit n'etre jamais venu dans ce quartier.
Chez lui il y a une dizaine de chats.
Cet objet ancien a une tres belle allure.
Sans savoir pourquoi elle lui donne une fleur.
Dans la maison de Paul il y a plusieurs cheminees.
Elle essaie en vain de recuperer son livre.
Elle est remarquable par la beaute de sa coiffure.
Comme il est puni on l'envoie dans la chambre.
Il a trouve son grenier infeste de mites.
Malgre ses efforts il reste tres mediocre.
Christophe a du mal a reparer sa tondeuse.
Il n'a jamais resiste a cette femme.
Elle a horreur d'aller dans le metro.
Elle pense qu'il manque de courage.

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