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Focusing on the N400: An exploration of selective attention during reading

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Abstract

In a series of two experiments, subjects read sentences wherein words were flanked in the lower visual field by irrelevant words (i.e., flankers). The visual angle between the words in the sentence and the flanker words was manipulated (i.e., 0.57°, 0.97°, 1.37°). Sentence endings were either congruent or incongruent; incongruent endings elicited a large N400 component. Flanker effects were observed for sentence final words on electrophysiological measures during the reading task and on subsequent recognition memory performance for sentence final and new words. For both measures, the flanker effect interacted with the congruency of the sentence ending as well as the visual angle between the sentence final word and its flanker. The largest and earliest flanker effects were observed for congruent endings at the smallest visual angle (0.57°); congruent endings and flankers in intermediate visual angle (0.97°) conditions displayed a similar flanker-related negativity but with a longer onset latency (490 vs. 280 ms). Congruent endings and their flankers in the largest visual angle (1.57°) conditions revealed no flanker effect.

Descriptors: N400, Flanker words, Selective attention, Reading, Vertical meridian

Spatial selective attention clearly plays an important role in natural reading because at any given moment a word at the point of fixation is surrounded by other words in both the horizontal and the vertical directions. The findings of Willows and MacKinnon (1973) indicate that unattended information can influence semantic processing during reading. They examined the consequences of interleaving irrelevant sentences between the lines of a double-spaced text as subjects were reading. Although the subjects could not recall the words comprising the irrelevant lines, their answers to questions following each text reflected an influence of the unattended material. Because it is difficult to tease apart the contributions of the many variables involved in such a complex task, research in this area has focused on a more tractable task in which subjects are presented with stimulus frames containing only one word to be attended surrounded by one or two words to be ignored (known as flankers). The primary motivation for these experiments has been the question of how effectively the analysis of a target word can be isolated from analysis of its flankers.

Shaffer and LaBerge (1979) addressed the question of whether or not flanker words are processed at a semantic level by presenting their subjects with a target word surrounded above and below by flankers (0.62° of visual angle). Target words had to be classified into four semantic categories, with two categories assigned to each hand. Each target word was positioned between two flankers that were either identical to it or belonged to one of the four categories. The extent to which flankers were processed was assessed by comparing response latencies to displays containing flankers assigned the same response as the target (compatible condition) with those containing flankers assigned a different response (incompatible condition). The results showed longer reaction times (RT) to the target words in the incompatible than in the compatible condition. Flanker stimuli from a different semantic category, but associated with the same response as the target, also produced interference. Both findings indicate that under these conditions subjects apparently cannot avoid processing the meaning of the flanking words.

Using a similar task, Broadbent and Gathercole (1990) showed that the visual angle between flanker and target word, the nature of the stimulus materials, and the relative timing between target and flanker word presentation all influenced the size of the flanker effect. For example, they obtained clear

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flanker effects with a small visual angle (0.6°, same as Shaffer & LaBerge, 1979) but no effects with a larger one (2.6°). Similarly, the reliable effects that appeared when flankers came from a small and highly familiar set of words repeated throughout the experiment were no longer apparent when subjects were presented with novel pairs of response categories and novel stimuli (i.e., those that were never repeated during the experiment). Broadbent and Gathercole also found that target categorization was more affected when the target preceded the flanker by 40 ms than when targets followed the flanker by 40 ms. This result suggests that processing of the flankers only begins after the target has been partially processed. These findings led Broadbent and Gathercole to conclude that although unattended information is not automatically fully analyzed, events occurring outside the spotlight of attention probably are not lost forever. Rather, the results favor a temporary delay in processing of unattended relative to attended information (see also Gathercole & Broadbent, 1987). Flankers seem to have their greatest impact when they are used repeatedly and are presented in close proximity to the target word, whose presentation they lag slightly.

Despite this progress in our understanding of flanker effects, several issues remain. First, it is unclear whether it is the priming of the target word that is the major contributor to the flanker effects found by Broadbent and Gathercole (1990). In their experiments, both the targets and the flanker words were either completely novel or were members of a highly familiar set. Second, greater precision in the manipulation of visual angle between attended and unattended information might shed more light on the issue of the possible delayed processing of events occurring outside the spotlight of attention. Third, a more direct measure of (semantic) processing would be useful in tracking the time course of flanker effects on-line. One possible candidate is the analysis of eye movements (see Rayner & Pollatsek, 1987, for a review). Another candidate is the event-related potential (ERP).

A negative ERP component elicited around 400 ms after the presentation of a word (i.e., the N400) is a sensitive index of semantic processing (for a review, see Kutas & Kluender, 1991; Kutas & Van Petten, 1988; Osterhout & Holcomb, in press). The amplitude of the N400 elicited by any given word is reduced by a preceding semantic context whether it consists of a sentence fragment, a phrase, or a single word, as long as it is appropriate (Bentin, McCarthy, & Wood, 1985; Kutas & Hillyard, 1980; Neville, Kutas, Chesney, & Schmidt, 1986). N400 amplitude is inversely proportional to off-line measures of semantic constraints such as cloze probability (Kutas & Hillyard, 1984). Similarly, Van Petten and Kutas (1990) showed that N400 amplitude to open class words is inversely correlated with the word's ordinal position in relatively simple English sentences. They interpreted this finding as a reflection of the buildup of constraints imposed by the sentence upon individual succeeding words. These results attest to the utility of ERPs as a measure of aspects of semantic processing. Can they also shed light on the effects of selective attention during semantic processing?

The effect of spatial selective attention on N400 was reported initially by McCarthy, Nobre, and Wood (1989). Subjects were instructed to press a button when members of a specified target category flashed to one visual field and to ignore similar words flashed to the other visual field; words were presented vertically at 4.5° to the left or the right of fixation. Attended words were associated with an N400-like ERP component (between 400 and 600 ms poststimulus), whereas unattended words were not. McCarthy et al. speculated that semantic processing of unattended words was attenuated in the unattended channel. Despite the relatively unnatural presentation mode (i.e., vertical) in this study, the clear N400 in response to words in the attended channel indicated that these words were semantically analyzed. Moreover, based on Broadbent and Gathercole's (1990) findings, the lack of any N400 effect for words in the unattended channel may be due in part to the large visual angle between attended and unattended words.

Otten, Rugg, and Doyle (1993) explored the effect of selective attention on word processing by examining the word repetition effect. Observed across a variety of tasks (e.g., fragment completion, identification, lexical decision), the repetition effect consists of a decrease in response latency to words on their second relative to first presentation. In the ERP, the most reliable effect of repetition is a sustained positivity from about 300 ms poststimulus for words on their second presentations (see Rugg, 1990, and Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991, for discussion on further subdivision of this repetition effect). Otten et al. (1993) presented their subjects with a lexical decision task consisting of stimulus frames containing two words, one of which was of the to-be-attended color. Both words were presented horizontally and were separated by less than I ° of visual angle. The first experiment showed that the repetition effect was present only if both presentations were in the attended color. Words repeated in the unattended color did not exhibit an ERP effect of the repetition. In a second experiment, Otten et al. (1993) precued the location of the to-be-attended word. The classical repetition effect was again most clear when both words were in the attended color. However, in this case the ERPs for words in the unattended color also showed some effect. Given the small visual angle, this result was expected, but surprisingly the ERP effect of the repetition of unattended words appeared to be qualitatively different from that observed for the attended words. When a word was unattended on both of its presentations, repetition was apparently associated with a negative- rather than a positive-going modulation. If reliable, the observation of a repetition effect with unattended repeated items suggests that unattended words can be processed at least to the level of their structural identity. In summary, the Otten et al. (1993) study, which used a small visual angle between attended and unattended stimuli, showed effects of unattended words, whereas the McCarthy et al. (1989) study, which used a larger separation, did not. These ERP data are thus consistent with behavioral studies in showing that the visual angle between attended and unattended information plays a major role in selective attention.

In the present study, we explored the effects of visual angle during spatial selective attention in a reading situation. A reading task was chosen for its relative naturalness as compared with the more traditional task, such as that of Shaffer and LaBerge (1979). Subjects were asked to read sentences with a high contextual constraint presented one word at a time. Except at very fast rates, this presentation mode has been shown not to affect comprehensibility (see Potter, 1984, for a review). Each word of the sentence was flanked in the lower visual field by a word of the same length. Subjects were required to attend to words in the upper field and to ignore the flanker words. Half the sentences ended with the anticipated congruent ending, and the other half ended with a semantically anomalous word (an incongruent ending). The flanker word presented simultaneously with the sentence ending was either the congruent or an incongruent ending. As in the Broadbent and Gathercole (1990) experiments, repeated (highly primed) and novel (not primed) sets of stimuli were used, and the results indicated that the degree to which the target word was primed was an important variable in evoking flanker effects. Our procedure is comparable to that of Broadbent and Gathercole in that congruent endings are highly primed by the preceding sentence context, whereas incongruent words are novel. However, our method has the advantage of allowing a comparison of flanker effects on primed and unprimed words within one experiment. Given the Broadbent and Gathercole results, we predicted that the flanker effects will be more prominent for the congruent than the incongruent endings. The visual angle between target and flanker words was manipulated as a between subject factor (0.57° and 1.37° in Experiment 1 and 0.97° in Experiment 2). Given the previous results, we expected the effects of flankers to be reduced as the visual angle increased.

Flanker effects were determined by examining ERPs for sentence endings and by comparing ERPs for frames where target and flanker are identical with ERPs for frames where target and flanker differ, thus allowing both the onset and magnitude of flanker effects to be measured. Differences in magnitude are probably related to the actual processing of a flanker, with the onset of the flanker effect probably being related to the time at which the processing of the flanker word becomes apparent. The onset of the flanker effect is therefore of particular interest to the issue of delayed processing of unattended events relative to attended information.

Experiment 1

Method

Subjects

Forty-eight native Dutch speakers (24 male and 24 female students, ages 19-23 years [M = 20.2 years]) were paid for their participation. All subjects were healthy and had normal or corrected-to-normal vision. With the exception of two of the men, all subjects were right handed. Two groups of 24 subjects each (12 women, 12 men) were formed, making a between-subject design possible. The subject groups did not differ in their verbal IQ as measured by the Groninger Intelligentie Test (t [46] = 1.61, n.s.).

Stimuli

One hundred twenty experimental sentences were chosen from a list of 157 sentences that had been completed by a group of approximately 100 students in a cloze procedure (Taylor, 1953; cloz e probability > 70%). The selected sentences formed the basis for six recognition tasks that began with the word-by-word presentation (500 ms/word) of sentences. Each sentence contained seven or eight words and ended with either the expected (i.e., congruent) or an anomalous (i.e., incongruent) word that had the same frequency of occurrence and the same length. After a short interval, a recognition task had to be carried out. Word length was always kept within 2° of the visual field. The white words, which had a height of approximately 0.2°, were presented on a dark background.

Flankers

Each word of a sentence was flanked in the lower visual field by a randomly chosen word of the same length (flanker words). The flanker words did not form a coherent sentence. Subjects were instructed not to read the flanker words but to direct their attention only to the words of the sentences. They were told this strategy would enhance their performance on the recognition task. The distance between the sentence and flanker words was either 0.57° or 1.37° (as measured from the upper to the lower edge of the displayed words) and was treated as a between-subjects factor. The sentence materials were constructed such that the word flanking the sentence final word was either the expected ending or was an incongruent ending. A full stop completing the sentence was presented with each sentence final word and flanker. Neither the sentence endings nor the simultaneously presented flankers were repeated during the sentence task. Because the sentences were either congruent or incongruent, any particular sentence ending fell into one of four categories (sentence ending/flanker type; see Figure la): (a) the two words were identical and both were congruent with the preceding context-congruent/congruent (CC); (b) the two words were different, with the ending congruent and the flanker incongruent --congruent/incongruent (CI); (c) the two words were identical and both incongruent-incongruent/incongruent (11); and (d) the two words were different, with the ending incongruent and the flanker congruent-incongruent/congruent (IC).

Presentation Sequence

A trial sequence was as follows. A blank screen displayed for 4,800 ms was followed by a fixation asterisk displayed at the to-be-attended location for 980 ms. Next came the first word of the sentence, followed immediately (i.e., stimulus onset asynchrony of 0 ms) by the rest of the words in the sentence, one word presented every 500 ms. The final word in the sentence was followed by a blank screen for 680 ms, after which the first frame of the next sentence was presented. After the last sentence, a blank screen (4,800 ms) both preceded and followed visual instructions for the recognition task (28,800 ms). The second blank screen was followed by the onset of the recognition task, which consisted of fixation asterisk (1,480 ms), stimulus word (1,480 ms), blank screen (480 ms) until the task was finished.

The six recognition tasks were presented in three blocks of two tasks each. One task included 20 experimental sentences that were preceded by one and followed by two filler sentences. The experimental sentences in a specific task were randomly assigned to a particular condition (i.e., five CC; five CI; five II, five IC). The filler sentences were introduced to prevent primacy and recency effects during the recognition task, which followed the sentences after 28.8 s.

In the recognition task the subject had to decide if the word was old (i.e., presented in the immediately preceding 20 sentences) or new (i.e., had not been among the words in the preceding 20 sentences). Only final words of sentences were included, a fact of which the subjects showed no awareness during the debriefing. The *old* response was given by lifting the index finger of the dominant hand, and the *new* response was given with the index finger of the other hand. The recognition task comprised 40 words (nouns) that could be divided into seven categories: an actual ending in the CC condition (WCC); an actual ending in the CI condition (WCI); an actual ending in the 11 condition (WII); an actual ending in the IC condition (WIC); a

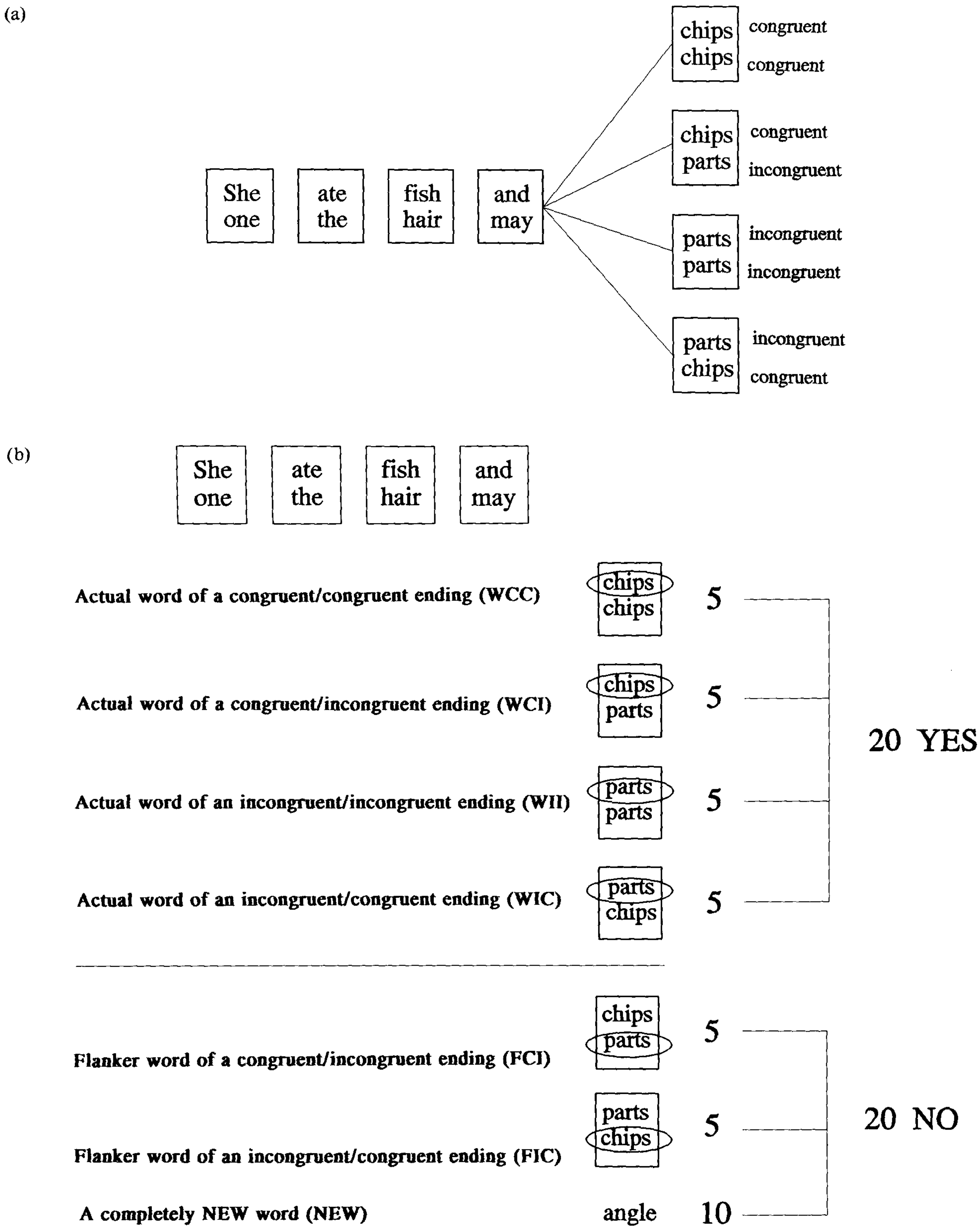

Figure 1. (a) A hypothetical example of the stimulus presentation during the reading task. Sentences of seven or eight words were presented one word at a time (500 ms/word). Subjects had to attend the upper word and ignore the lower one (i.e., the flanker). (b) Categories used in the recognition task. The boxes represent the stimulus frames containing the words. The circled words are the described category; only these words were tested during the recognition task. Thus, during the recognition task single words had to be judged as having been presented previously during the reading of the sentences in the to-be-attended part (i.e., upper part) of the display. Because flankers were not supposed to be read, subjects had to respond no to those items.

flanker for the CI condition (FCI); a flanker for the IC condition (FIC); and a completely new word (NEW) (see Figure I b). In other words, the to-be-attended words (old words: WCC, WCI, WII, WIC) as well as the to-be-ignored words (new words: FCI, FIC) were tested for recognition.[1]

Two versions were made of each block that differed only with respect to congruency and incongruency of the sentence endings (for both the attended and flankers), which was switched between versions. Subjects received either Version 1 or Version 2 of all blocks. Thus, a total of 60 congruent (30 CC and 30 CI) and 60 incongruent (30 11 and 30 IC) experimental sentences were read, and 240 words were judged for recognition.

Procedure

An experimental session lasted 2-3 hr. The subjects were tested on verbal IQ and trained on the experimental task. They were seated in a dimly lit, sound-attenuated, electrically shielded room facing a cathode ray tube (white on black) at a distance of approximately 110 cm. Instruction was given to read only the sentence (i.e., the upper part of the display) and to ignore the flanker words because these would interfere. Training included a gradual lengthening of the task from 10 sentences and 20 recognition words to the experimental length of 23 sentences and 40 recognition words. Subjects were aware that their recognition memory would be tested. None of the material presented during training was used in the experimental session.

Recordings

The electroencephalogram (EEG) was recorded with Ag-AgCl electrodes from Fz, Cz, Pz, Oz, right temporal, and left temporal, each referred to the right mastoid. Temporal electrodes were placed 75% of the distance from Cz to T3 on the left and T4 on the right. The electrooculogram (EOG) was recorded bipolarly between electrodes situated on the outer right canthus and above the eyebrow of the right eye. Electrode resistance was kept under 2 kOhm. The signals were amplified, hand-pass filtered between 0.05 and 35 Hz, and digitized at a rate of 100 Hz.

Data Analysis

Average ERPs, starting 280 ms before and lasting 1,000 ms after stimulus presentation, were computed for each electrode position for the four stimulus categories related to the sentence final words (CC, CI, II, IC).

[1]The simultaneous presentation of WCI and FCI (as well as WIC and FIC) seems to present an interesting possibility for testing the efficacy of the attentional selection. Specifically, whenever the flanker word (e.g., FCI) was recognized and the to-be-attended word (e.g., WCI) was not, it could be argued that subjects were switching their attention. Alternatively, whenever the to-be-attended word was recognized and the flanker was not, it could be argued that subjects had been able to selectively focus. If recognition of to-be-attended and flanker words covaried, then either (a) subjects were able to focus their attention but the flanker intruded or (b) subjects were dividing their attention. Unfortunately, in the present experiment, this analysis would be confounded by the fact that a highly constrained sentence will always activate its expected ending in memory. That is, whenever an IC ending was presented, the flanker was highly expected and would therefore be recognized more often and more quickly on this basis alone. However, the problem for CI endings is that semantic interference would also occur if subjects were switching their attention to the flanker. To deal with this confound, it would have been necessary to include another ending type, namely two different incongruent words.

Approximately 5% of the trials were excluded from the average because of ocular and amplifier saturation artifacts (EOG rejection above 50 μV). Averages were aligned to a 100-ms prestimulus baseline. To assess slow potential shifts (N400 and slow wave [SW]), the mean amplitudes of 33 epochs of 30 ms each were computed starting at stimulus presentation (e.g., interval 20 is a mean of 10, 20, and 30 ms; interval 50 is a mean from 40 to 60 ms, etc.). In an additional analysis investigating scalp distribution of several ERP components, the scaling procedure described by McCarthy and Wood (1985) was applied: computed area measurements were divided by the square root of the sum of the squared voltages across the relevant electrode sites separately for each stimulus category for each individual subject. Finger lifting responses, between 290 and 1,500 ms after stimulus onset, were scored as hits. From these data, mean RTs, the standard deviation of RT (SD), and the number of correct responses in each recognition category were computed.

All dependent variables were analyzed using SPSSPC+ multivariate analyses of variance (MANOVAs). The multivariate approach to repeated measurements was used (O'Brien & Kaiser, 1985; Vasey & Thayer, 1987), thereby avoiding problems concerning sphericity. Within-subject variables were version (1 or 2), congruency of sentence ending (congruent or incongruent), and flanker type (same as sentence ending or different). Because this experiment also included an additional task in which selective attention on the vertical meridian was investigated by means of letters (see Gunter, Wijers, Jackson, & Mulder, 1994), a task order variable was included. No main effect nor interactions with this variable was found in any of the analyses. The between-subject variables were task order (reading task first or reading task second) and angle (0.57° or 1.37°). The first analysis carried out on the interval data included electrode (Fz, Cz, Pz, Oz, Tr, TI) as a within-subject variable. All other analyses of the interval data were carried out for each electrode position. Planned comparisons of congruent and incongruent stimuli for both distances separately were carried out based on the study by Broadbent and Gathercole (1990). Whenever significant effects in a particular range are reported, all mean amplitude variables in this range showed significant effects ($p < .05$). Effects will only be presented when two or more successive amplitude variables were significant.

Old and new words of the recognition task were analyzed separately. RT and percent correct of the old words were analyzed using MANOVAs with a design similar to that for the interval data. Additionally, the RT and percent correct of the new words were analyzed using planned comparisons on FCI versus NEW and FIC versus NEW. The FCI versus NEW comparison reflects flanker interference proper. Because the FCI was incongruent with the sentence ending, it was not semantically related to the preceding sentence context and should not, if it was completely ignored, be different from processing of completely NEW items. The FIC versus NEW comparison, however, is a mixture of flanker activity and memory processes because the FIC was also the expected ending of the preceding sentence fragment. Thus, besides the flanker interference, we expected to find semantic interference. Gunter, Jackson, and Mulder (1992) showed that if a sentence ending was expected but not presented (as for incongruous sentences), this item was associated with an increased RT and decreased accuracy in a subsequent recognition test. This effect was attributed to interference caused by the activation of the expected word in semantic memory.

Results

Behavioral Data

Analyses for the old words: WCC, WCI, WII, and WIC. A main effect of congruency indicated that the congruent endings (WCC and WCI) were recognized 40 ms more slowly than were the incongruent endings (WII and WIC; see Table 1) ($F[1,40] = 26.2$, $p < .0001$). An interaction of Distance X Flanker Type indicated that in the 0.57° condition there was a clear RT effect of the type of flanker stimulus presented together with the sentence ending ($F[1,40] = 7.68$, $p < .008$). Additional analyses carried out on the two distances separately revealed that only the 0.57° condition showed a main effect of flanker. RT increased by approximately 45 ms when the flanker word was different from the word presented at the attended location ($F[1,20] = 15.11$, $p < .001$). Incongruent endings were recognized 12% better than congruent endings, as indicated by a main effect of congruency ($F[1,40] = 54.2$, $p < .0001$).

In summary, the behavioral data for the old words showed that incongruent sentence endings were recognized more quickly and more accurately than were congruent ones. Only when the flanker word was relatively close (as in the 0.57° condition) did the flanker influence behavioral responses to the sentence endings.

Analyses for the new words: FCI, FIC, and NEW. FCI and NEW items were compared to investigate flanker interference (see Table 1). RTs showed a Distance X New Word Type interaction ($F[1,40] = 9.4$, $p < .004$), indicating that in the 0.57° condition FCI items were recognized more slowly than were NEW items (29 ms, $F[1,20] = 10.44$, $p < .004$). This was not the case in the 1.37° condition ($F[1,20] = 1.2$, n.s.). Percent correct also showed a Distance X New Word Type interaction ($F[1,40] = 9.88$, $p < .003$), indicating that in the 0.57° condition, FCI items were recognized less accurately than were NEW items (12%, $F[1,20] = 25.5$, $p < .0001$). This drop in performance was not present in the 1.37° condition ($F[1,20] = 2.0$, n.s.).

The FIC and NEW items were compared to investigate additional effects due to semantic interference. Both RT and percent correct showed a main effect of new word type, indicating that FIC items were recognized more slowly and less accurately than were NEW items (98 ms, $F[1,40] = 65.07$, $p < .0001$; 27%, $F[1,40] = 150.7$, $p < .0001$). No main effect or any interaction with distance was found.

Table 1. *RT and Percent Correct During the Recognition Task for Words at Different Visual Angles*

	Reaction time (ms)		Percent correct	
Condition[a]	0.57°	1.37°	0.57°	1.37°
WCC	947	942	64	67
WCI	1,003	965	63	67
WII	909	932	76	79
WIC	944	912	75	76
NEW	949	958	89	87
FCI	978	947	77	84
FIC	1,043	1,060	61	61

[a]Actual endings of sentences (W) or flanking words (F) in congruent (C) or incongruent (I) combinations or completely new words (NEW).

In summary, the behavioral data for the new words demonstrated that if the flanker word was not identical to the sentence ending, the flanker influenced recognition performance by slowing RTs and decreasing percent correct (i.e., flanker interference). This effect however was present only when the visual angle between the flanker and sentence final word was small (as in the 0.57° condition). By contrast, semantic interference was evident regardless of the distance between the sentence final word and the flanker.

ERP Data

Sentence endings. Analyses carried out across all subjects and all electrodes showed significant main effects of electrode between 20 and 980 ms (for all intervals, $p < .0001$). Interactions of Electrode X Congruence were present between 200 and 980 ms. The effect of congruence can be seen in the grand average waveforms in Figure 2. Between 320 and 560 ms after stimulus presentation, there is a negative-going shift (the N400) for incongruent words as compared with congruent words (for all intervals, $p < .0001$). After approximately 650 ms, a positive-going shift (the SW), lasting to the end of the epoch, is present for the incongruent endings (for all intervals, $p < .001$, typically $p < .0001$). Both shifts are broadly distributed, the former maximal at Cz and the latter at Pz. There were significant interactions of Distance X Flanker Type (380-470 ms) and Congruency X Flanker Type (380-440 ms) in the region of the N400 (for all intervals, $p < .05$).

This overall analysis showed that there was an N400 and an SW, and the N400 was affected by flanker type and distance. To look at the nature of the interaction between electrode and experimental conditions, the data for each electrode were analyzed separately.

Effects of distance and flankers. The analysis carried out for each electrode showed clear effects of congruency (N400 and

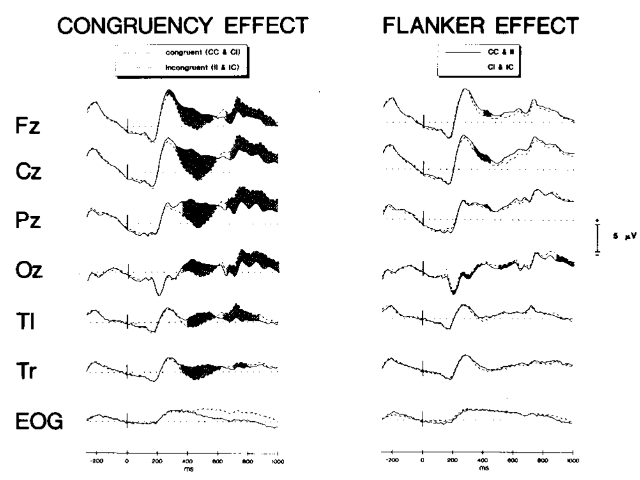

Figure 2. ERPs based on the data of both distance groups together. The left panel indicates the effect of congruency (N400 and SW). The solid line is an average ERP for the congruent ending (CC and CI). The dashed line is the average for the incongruent ending (11 and IC). The right panel indicates the effect of flankers. The solid line is the case where the flanker stimulus is the same as the attended word (CC and II). The dashed line is the ERP for the frames in which attended and flanker information differs (CI and IC). The shaded areas show a significant (p < .05, typically p < .001) difference between the two categories.

Table 2. *ERP Results (ms) for Flanker Effects and Distance*[a]

Electrode	Flanker X Distance interaction	Flanker effect 0.57°	Flanker effect 1.37°
Fz	350-380	320-410, 680-740	
Cz	290-500, 590-680	260-980	
Pz	380-500	380-440	
Oz	350-380		220-370, 850-940
T1			
Tr	410-470, 830-980	380-440, 680-980	

Note: All *p*s < .05; typically *p* < .001.
[a]Effects at two visual angles.

SW) and flanker type (see Figure 2). The main effect of flanker as found at Fz, Cz, and Pz consisted of a negative shift if the flanker was not the same as the sentence ending (i.e., CI and IC) as compared with the situation where the flanker and the sentence ending were identical (CC and II). Although this effect was reversed at the occipital site, we will call it flanker negativity. Interactions of Distance X Flanker (see Table 2) were also found, indicating that the flanker negativity was not the same in the 0.57° and the 1.37° conditions. Analyses carried out for each distance showed that the flanker negativity was particularly evident in the 0.57° condition (see Table 2). Interactions of Congruency X Flanker were also present in the main analysis (see Table 3), indicating that the flanker negativity was mainly present in the congruent endings. This indication was substantiated by separate analyses for congruent and incongruent endings (see Table 3). Although no three-way interaction of Distance X Flanker X Congruency was present in the main analysis, separate analyses were carried out on congruent and incongruent stimuli for each distance. The study by Broadbent and Gathercole (1990) clearly points toward the plausibility of such a planned comparison analysis. In the 0.57° condition, there was a very clear flanker negativity, which was mainly present in the congruent endings (Figure 3a). As might be expected on the basis of the Flanker X Distance interaction, there was no flanker negativity in the 1.37° condition (see Figure 3b).

In summary, the ERP data indicated that the flanker stimuli did have an influence during the reading task. The ERPs for congruent sentence endings were more negative if the flanker was not the same as the congruent sentence ending, but only in the 0.57° condition. Effects of congruency (N400 and SW) however were present in both the 0.57° and the 1.37° conditions.

Discussion

The behavioral and ERP data demonstrate that irrelevant material (i.e., flankers) intruded on the processing of attended material only when flanker and sentence ending were close to each other in space (i.e., 0.57°). These data are in accordance with Broadbent and Gathercole's (1990) finding of clear nontarget effects at only close (0.6°) separation. Our data also suggest that the spotlight of attention is narrower than the 2.6° found by Broadbent and Gathercole (1990), because no flanker effect was present at the 1.3° separation. However, both distances did show a clear semantic interference effect, indicating that the expected ending was activated equivalently in semantic memory in both conditions.

Recently, Inhoff and Briihl (1991) measured eye movements during a task similar to that of Willows and MacKinnon (1973). Subjects were presented with two lines of a text; the upper line was part of an attended message and the lower line was part of an ignored message. After each passage, subjects answered six multiple-choice questions, half of which queried the attended material and half of which referred to the ignored text. The results replicated Willows and MacKinnon's finding that subjects obtained useful information from the supposedly ignored text. However, the eye-fixation records showed that readers occasionally fixated the to-be-ignored text. Moreover, when these fixated segments of the ignored text were excluded from the analyses, the effect disappeared. Thus one could argue that because our stimuli were presented at a rate of 500 ms/word the observed intrusions may be a consequence of tiny eye movements toward the unattended stimuli.

To assess the likelihood that our results could be explained in a similar fashion, we conducted a behavioral study on 80 sub-

Table 3. *ERP Results (ms) for Flanker Effects and Congruency*

Electrode	Flanker X Congruency interaction	Flanker effect Congruent only	Flanker effect Incongruent only
Fz	320-440, 860-980	320-440, 530-560	
Cz	260-290, 500-590, 800-980	260-440, 500-620, 710-980	
Pz	800-980	380-440, 590-620, 890-980	890-980
Oz	440-590, 680-980		200-650, 800-980
Tl		380-440	
Tr		350-440	

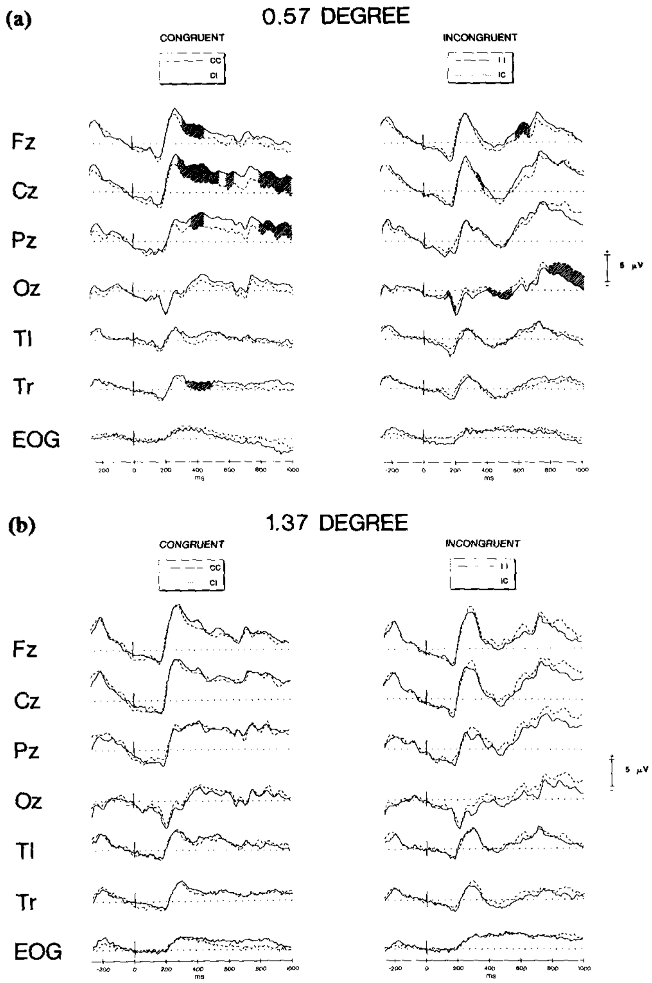

Figure 3. The effects of flankers during the 0.57° (a) and the 1.37° (b) condition for congruent and incongruent endings. The solid line shows the case where the flanker stimulus is the same as the attended word (CC or 11). The dashed line shows the ERP for the frames in which attended and to-be-ignored information differs (Cl or 1C). The shaded areas show a significant ($p < .05$, typically $p < .001$) difference between the two categories for the 0.57° condition.

jects; half were exposed to the same presentation format as in Experiment 1 (500 ms/word) and the other half were given a presentation rate of 50 ms/word with a blank screen of 450 ms between words? This alternative presentation format did not allow subjects enough time to shift their gaze downward to read the flanker word. The global pattern of the behavioral results from Experiment 1 was replicated; the only difference between the experiments was a greater sensitivity of the percent correct than the RT measures in the replication. Significant flanker interference was found only in the 0.57° condition, but the semantic interference was clearly visible at both distances. The main conclusion therefore is that presentation format had no effect, which in turn suggests that it is unlikely that eye movements can explain the flanker effects found in Experiment 1.

[2]Further information about this experiment can be obtained from the first author.

Broadbent and Gathercole (1990) proposed that events occurring outside the spotlight of attention are not shut out forever but are merely delayed in processing. Our 1.3° condition may involve too large a distance to yield even a relative flanker effect, but perhaps an intermediate distance level could provide more insight into the mechanisms of the flanker intrusion. Decreasing the visual angle would result in increasing the probability of a significant flanker negativity, whereas this effect should be delayed relative to that observed in the 0.57° situation. However, if the spotlight of attention is characterized by a decrease in intensity from the center to the periphery (i.e., if there is a gradient of attention; Shulman, Sheehy, & Wilson, 1986; Shulman, Wilson, & Sheehy, 1985) and subjects experienced a visual angle of 0.97° between attended and unattended information, then we might expect intermediate results, namely a smaller flanker negativity that starts at the same time as the 0.57° condition. However, if spatial attention is distributed evenly within the spotlight (Eriksen & St. James, 1986; Eriksen & Yeh, 1985), we would expect to find either a flanker negativity similar to the one observed in the 0.57° condition or none at all as observed in the 1.37° condition.

Experiment 2

Method

The same materials, methods, and procedures were used as in Experiment 1; however, the visual angle between the sentence ending and flanker word was 0.97°.

Twenty-four native Dutch speakers (12 male and 12 female students, ages 19-23 years [$M = 20.5$ years]) were paid for their participation. All subjects were healthy and had normal or corrected-to-normal vision. With the exception of one male and one female subject, all subjects were right handed. None of the subjects had taken part in the previous study. Verbal IQ of this subject group did not differ from that of the two groups tested in Experiment 1 ($F[2,69] = 4.04$, n.s.).

Results

Behavioral Data

Analyses of old words: WCC, WCI, WII, and WIC. A main effect of congruency indicated that the various congruent endings were recognized 40 ms more slowly than were the incongruent ones (see Table 4; $F[1,20] = 9.64$, $p < .006$). A main effect of flanker type indicated that if flankers and sentence endings

Table 4. *RT and Percent Correct During the Recognition Task for Words at 0.97° Visual Angle*

Condition[a]	RT	Percent correct
WCC	923	58
WCI	923	56
WIl	853	76
WIC	914	69
NEW	879	88
FCI	915	79
FIC	986	64

[a]Actual endings of sentences (W) or flanking words (F) in congruent (C) or incongruent (1) combinations or completely new words (NEW).

were the same, the recognition of the sentence ending was faster (F [1,20] = 4.33, $p < .051$). This effect however was seen primarily for incongruent sentence endings (Congruency X Flanker Type interaction, 61 ms, $F[1,20] = 5.04$, $p < .036$). A main effect of congruency indicated that incongruent endings were more likely to be recognized than were congruent ones (16%, $F[1,20] = 83.8$, $p < .0001$). A main effect of flanker indicated that if flankers were the same as sentence endings, the percent correct was greater (5%, $F[1,20] = 5.06$, $p < .036$).

In summary, subjects recognized incongruent endings better than congruent ones. There were clear effects of flanker, especially in percent correct recognition.

Analyses of new words: FCI, FIC, and NEW. First, FCI and NEW items were compared. Both RT and percent correct showed a main effect of new word type, indicating that the FCI stimuli were recognized more slowly and less often than were NEW stimuli (RT: 36 ms, $F[1,20] = 5.14$, $p < .035$; correct: 9%, $F[1,20] = 27$, $p < .0001$).

Next, FIC and NEW items were compared to see whether or not an effect of semantic interference was present in addition to the effect of flanker interference. Both RT and percent correct showed a main effect of new word type, indicating that the FIC stimuli were recognized more slowly and less often than were NEW stimuli (RT: 107 ms, $F[1,20] = 4.17$, $p < .035$; correct: 24%, $F[1,20] = 201.3$, $p < .0001$).

In summary, the behavioral data showed clear flanker interference effects that resemble those of the 0.57° condition. Moreover, semantic interference effects were again clearly present.

ERP Data

Sentence endings. An analysis carried out across all electrodes and all experimental conditions indicated that separate analyses for each electrode were justified because clear Electrode X Experimental Condition interactions were found. In these more detailed analyses (see Table 5), reliable effects of congruency were found in the area of the N400 (approximately 350-530 ms) and the SW (approximately 650-980 ms). In addition, Congruency X Flanker interactions were found. Additional analyses for congruent and incongruent sentence endings separately were conducted. Flanker negativity was present only for congruent sentence endings (Figure 4). At the central electrode, the flanker negativity became significant after approximately 500 ms. As in Experiment 1, the effect of flankers was composed of a negative shift when the flanker word was not the same as the sentence ending (i.e., CI and IC).

Discussion

The global pattern of results found in Experiment 1 also was observed in Experiment 2. Both the behavioral and the ERP data resemble the effects previously reported for the 0.57° condition. However, the ERP flanker effect (i.e., the negativity associated with flankers in association with congruent endings) began approximately 210 ms later for 0.97° than for 0.57° visual angle.

Scalp Distribution: An Additional Analysis

On visual inspection, the scalp distribution of the flanker negativity resembled that of the N400. To explore this resemblance further, we conducted some additional analyses. Because the flanker negativity is a difference wave (CC - CI), we likewise defined the N400 effect as a difference between CC and II. To deal with the fact that the flanker negativity showed up later in time in the 0.97° condition than in the 0.57° condition, we used the following logic. Because the N400 effect was the same at all three distances, we measured a 200-ms interval when all three conditions showed a significant effect of congruency, namely, between 350 and 550 ms. In this same area, the flanker negativity of the 0.57° condition was also clearly present. Because the flanker negativity was delayed in the 0.97° condition, we took an area between 650 and 850 ms to estimate the flanker effect in this condition. In the prescribed areas, difference potentials were computed for the N400 (i.e., CC - II) and flanker negativity (CC - CI) for all three distance conditions. These values were scaled using the method of McCarthy and Wood (1985) to account for possible differences in the source strengths between the two ERP components (see Figure 5). Analyses were carried out using MANOVAs with electrode (Fz, Cz, Pz, Oz, Tl, Tr) and kind of negativity (N400/flanker) as variables. An interaction between electrode and negativity would indicate that the scalp distribution was different between N400 and flanker activity.

The first analysis, which incorporated all three spatial separations, revealed interactions of Separation X Electrode

Table 5. *ERP Results (ms) for Main Effect of Congruency and Congruency X Flanker Interactions*

Electrode	Main effect	Interaction
Fz	320-470,590-980	
Cz	320-530, 650-980	740-920
Pz	350-530, 650-980	740-920
Oz	380-500, 740-980	680-980
Tl	380-530,620-890	
Tr	320-560,620-980	170-290

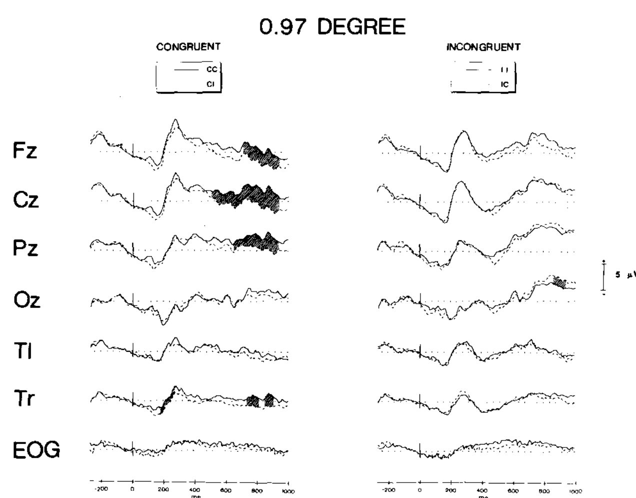

Figure 4. The effects of flankers during the 0.97° condition for congruent and incongruent endings. The solid line shows the case where the flanker stimulus is the same as the attended word (CC or II). The dashed line shows the ERP for the frames in which attended and to-be-ignored information differs (CI or IC). The shaded areas show a significant ($p < .05$, typically $p < .001$) difference between the two categories.

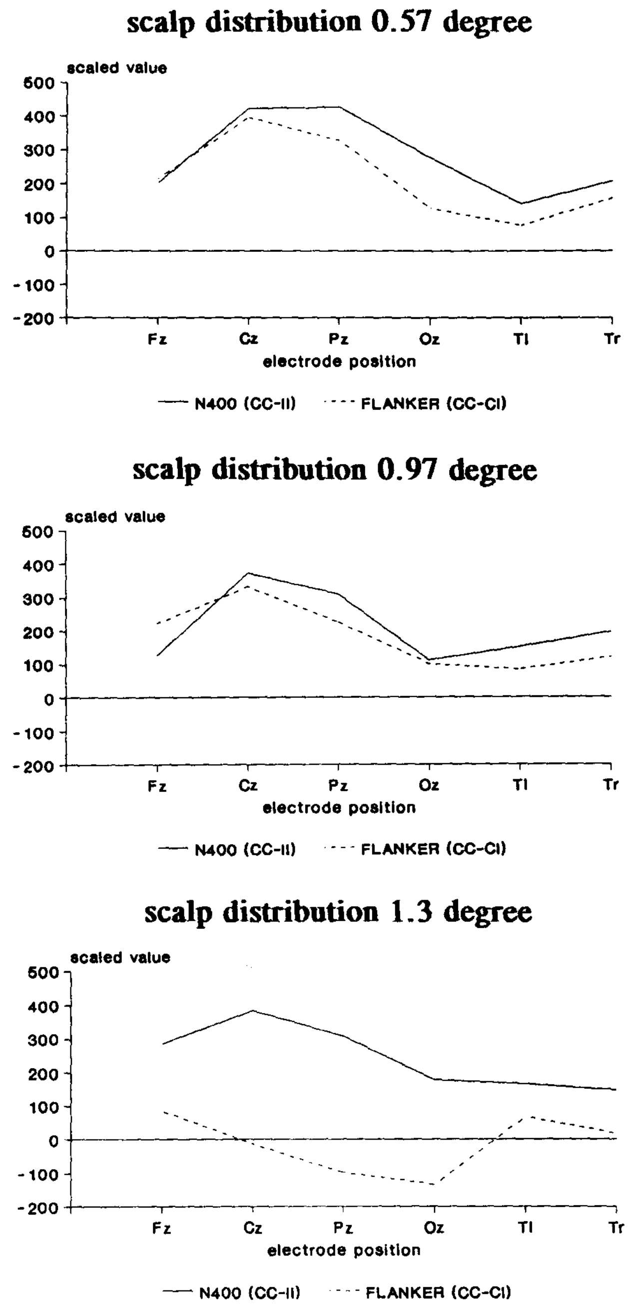

Figure 5. Scalp distribution of the flanker negativity (CC - Cl) and the N400 (CC - 11) for all three distance conditions after McCarthy and Wood (1985) scaling.

(F[10,132] = 2.81, p< .003), Separation X Negativity (F [2,69] = 11.9, p < .003), and Electrode X Negativity (F [5,65] = 4.9, p < .001) and a three-way interaction of Separation X Negativity X Electrode (F [10,132] = 3.75, p < .0001). To investigate these interactions, separate analyses were carried out on each condition (i.e., 0.57, 0.97, 1.37°). The 0.57° condition showed a main effect of electrode (F[5,19] = 4.6, p < .006) and a marginally significant main effect of negativity (F [1,23] = 3.27, p < .087). There was, however, no interaction between electrode and negativity (F< 1). The 0.97° condition only showed a significant main effect of electrode (F[5,19] = 4.9, p < .005). The interaction between electrode and negativity was not significant (F [5,19] =1.2, n.s.). The 1.37° condition showed a main effect of negativity (F[1,23] = 22.5, p < .0001) and a significant Electrode X Negativity interaction (F[5,19] = 2.64, p < .057).

In summary, no interaction effects of electrode and negativity were found in the 0.57° and 0.97° conditions, indicating that no differences between the scalp distribution of the flanker negativity and N400 were found.

General Discussion

In this series of experiments, we explored the effects of spatial selective attention during the reading of syntactically simple sentences. Flanker effects were found to depend on the visual angle between flankers (unattended) and sentence endings (attended) and on the congruency of the sentence endings. On the whole, ERPs elicited by congruent endings showed a flanker effect that consisted of a negativity with a scalp distribution resembling that of the N400. The onset of this flanker negativity depended on the visual angle between sentence ending and the flanker word; the effect started at 290 ms in the nearest (0.57°) condition and at 500 ms in the intermediate (0.97°) condition. There was no flanker ERP effect in association with the largest (1.37°) visual angle.

Behavioral data from the postreading recognition task essentially confirm the ERP data. Only the two closely spaced flankers resulted in interference effects. Old flanker words that had no semantic relationship to the sentence endings (i.e., FCI) took longer to reject and resulted in more errors than did new word items. In contrast, a reliable effect of semantic interference was observed at all three distances. In this case, old flankers that were the expected sentence ending (i.e., FIC) showed an increased RT and a decreased percent correct during correct rejection. This result replicates findings from an earlier experiment (Gunter et al., 1992), where correct rejections of expected but never actually presented words also led to an increase of RT and a decrease of percent correct in a recognition task that followed sentence reading. It is reasonable to attribute this effect to the activation of the expected word in semantic memory. The semantic interference was in addition to the flanker interference, if present. Both the flanker and the semantic interference effects were replicated in a separate experiment. The results of this experiment, which used very rapid presentation durations, also demonstrated that tiny eye movements toward the to-be-ignored words (i.e., the flankers) could not account for the flanker effects.

At first sight, the lack of a flanker effect for incongruous sentence endings seems hard to interpret, particularly because the FIC items elicited a clear semantic interference effect. The semantic interference effect is not flanker related because it also appears in situations where no flankers were used (Gunter et al., 1992). Therefore, there is no reason for expecting a flanker effect in the incongruent sentences. The absence of flanker negativity in the response to incongruent sentences is consistent with the findings of Broadbent and Gathercole (1990), demonstrating that the attended information is processed first (their Experiment 1) and flanker effects emerge only if stimuli are used repeatedly (their Experiments 2 and 3). Repeated stimulus sets probably result in a highly primed set of lexical entries. Only these highly primed words displayed flanker effects. Because the priming of attended and unattended material in our experiment was manipulated independently, it was possible to explore this idea further. Incongruent sentence endings are not (highly) primed in semantic memory, and they do not show any flanker effect. Congruent sentence endings, however, are highly primed in semantic memory, and they do display a flanker effect.

The time course of the flanker negativity in the present experiments depended on the visual angle between attended and unattended locations. It is therefore tempting to speculate that this (gradual) intrusion of flanker words supports the suggestion by Broadbent and Gathercole (1990) that events outside the attentional spotlight are not shut out completely but are merely delayed in processing. The flanker negativity might thus reflect the gradual infiltration of the unattended material into the spotlight. However, the onset of the flanker negativity probably does not reflect the actual start of flanker processing but rather the beginning of the difference between the processing of the CC and CI frames. The processing of the flanker may have started earlier but may not yet have been evident in the ERP (e.g., Rugg, 1991; Wijers, 1989). One could claim, however, that the intermediate value of the flanker negativity in Experiment 2 was due to the fact that the subject sometimes behaved as if the flanker were close and sometimes as if it were far away from the target. If this were the case, however, one would expect to find a smaller flanker negativity with an onset similar to that of the 0.57° condition. However, the onset of the mixed effect (i.e., mean of small and large distance) has approximately the same onset as the 0.57° condition (Figure 2) and is not delayed as in the 0.97° condition. The present data therefore favor the *gradual intrusion* explanation.

One could argue that, in the present experiment, visual acuity and the effects of attention are confounded. When a target stimulus is displaced toward the periphery of the retina, acuity rapidly decreases, even within the fovea (e.g., Olzak & Thomas, 1986). Within this area (approximately 1.5-2.0°; see Hood & Finkelstein, 1986), the acuity will decrease from approximately 1.5 in the center of vision to approximately 1.3 at the edge of the fovea (i.e., decimal acuity; this is a Snellen fraction of 20/10 to approximately 20/15; see Olzak & Thomas, 1986). Normal acuity is 1.0 (i.e., 20/20). Thus, the larger the spatial separation between attended and unattended words, the worse the acuity of the unattended word. Eriksen and Schultz (1977) showed that RT for target identification gradually increased when a capital letter was moved from the center of the fovea to a locus of 3° left or right of this center of vision. However, a 1 ° movement led only to a 13-ms increase in RT (418 vs. 431 ms). Because our stimuli were presented within the fovea, it seems unlikely that such small reduction of acuity could lead to the large flanker effects we found.

Another problem to consider in the present experimental design is that the critical comparisons demonstrating the flanker effects (i.e., CC vs. CI and 11 vs. IC) could reflect a physical mismatch process instead of differences due to actual processing of the flankers. According to this view, the ERP effects would reflect the fact that in the CC and 11 conditions the sentence ending and flanker were physically identical, whereas in the CI and IC conditions they were different. However, a strict physical mismatch account would predict similar effects whether sentence final words were congruent or incongruent. Because this was not the case, the flanker effects found probably were not simply a consequence of a physical mismatch. Use of various nonidentical flankers would provide data relevant to this interpretation. However, this design is very hard, if not impossible, to set up for the congruent endings because, as a result of the high close probability adopted, only one response can be the expected one and a different word will always be relatively incongruent with the preceding context. Incongruent endings experience this dilemma to a much smaller extent.

The functional nature of the flanker negativity remains uncertain. It resembles the N400 in its scalp distribution. Their possible equivalence, however, will have to be substantiated by studies using more electrodes or perhaps different techniques (e.g., MEG) to localize the source(s) of the N400 and flanker negativity more reliably. However, if the flanker effect and the N400 have the same functional basis, one might argue that this negativity is related to semantic processing. One might further argue that the flanker word was semantically processed and elicited an N400-like component to the extent that it was incongruent with the sentence ending. The N400-like component only occurred when target and flanker were closely spaced, which points to a nonoptimal selection process (leakage of unattended information into the spotlight). In addition, only congruent endings showed flanker effects, which might reflect the fact that the processing of an incongruent word takes so much time/resources that none remain available for processing the flankers.

To what extent does flanker negativity, like the N400, depend on the degree to which a word is semantically primed by prior context? As shown by Kutas, Lindamood, and Hillyard (1984), a semantically anomalous word has a smaller N400 when it is related to the sentence's expected ending than when it is not (for "The pizza was too hot to . . . ," cry was associated with a larger N400 than was *drink; eat* was the expected ending). If the flanker negativity taps into the same process as the N400, then one would expect the same relation. The use of flanker words that are associated with the congruent ending might shed some light on this question. In addition, results from a condition with incongruent endings flanked by nonidentical incongruent flankers could support the finding that flanker effects are only present for congruent endings.

Recent behavioral experiments suggest that selective attention is accomplished by a combination of facilitated processing of attended information and inhibition of the processing of unattended information (e.g., Driver & Tipper, 1989; Yee, 1991). Our ERP flanker effect may consist of the sum of such facilitory and inhibitory effects. Employing a neutral flanker condition (with a nonword or a row of Xs) might be one way of illuminating this issue.

We have replicated the behavioral experiments of Broadbent and Gathercole (1990) using on-line physiological measurements and have shown that flanker effects depend on the visual angle between attended and unattended information and on the content of the attended information. Moreover, we have shown that this angle dependency expressed itself as a time constraint; the smaller the visual angle the earlier in time the flanker effect appeared. In conclusion, although some uncertainty still remains about the most appropriate explanation for these data, what we have offered to the debate on mechanism of spatial selective attention is converging physiological evidence indicating that semantic processing of unattended information depends on its spatial relationship with the attended material and on the content of the attended information.

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