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Against Parafoveal Semantic Preprocessing During Eye Fixations in Reading*

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ABSTRACT Subjects' eye movements were recorded as they read sentences, and a display change occurred before they fixated on a critical target word (*song*). In the target word location one of four alternative previews was initially present: the target word itself, a word that was semantically related to the target (*tune*), a word that was unrelated to the target (*door*), or a nonword that was visually similar to the target (*sorp*). When the reader's eye movement crossed over an invisible boundary location, the initially displayed preview was replaced by the target word. If automatic semantic preprocessing of parafoveal words occurs in reading, the presence of a semantically related word should facilitate processing of the target word relative to the unrelated word. While the visually similar preview facilitated processing almost as much as the target itself, there was no difference between the semantically related preview and the unrelated preview, even though the semantically related words used in the study produced strong facilitation effects in a standard priming experiment. The results of the study are thus inconsistent with a model in which words in parafoveal vision are semantically preprocessed. It was concluded that the meanings of unidentified parafoveal words do not modulate our reading performance.

RÉSUMÉ Les mouvements oculaires de sujets étaient enregistrés pendant la lecture de phrases et un changement dans la présentation survenait avant qu'ils aient fixé un mot cible critique (*song*). Lors de la localisation du mot cible, l'une de quatre possibilités de pré-présentation était présente au commencement: le mot cible lui même, un mot sémantiquement relié au mot cible (*tune*), un mot sans relation au mot cible (*door*), ou un mot sans sens visuellement semblable au mot cible (*sorp*). Lorsque le mouvement oculaire du lecteur traversait un endroit limite invisible, le stimulus présenté au début était remplacé par le mot cible. Si un prétraitement sémantique automatique de mots en parafovéal survenait pendant la lecture, la présence d'un mot sémantiquement relié devrait faciliter le traitement du mot cible par rapport au mot non relié. Alors que la pré-présentation visuelle semblable facilitait le traitement presque aussi bien que le mot cible lui-même, il n'y avait pas de différence entre les pré-présentations reliées sémantiquement et celles non reliées même si les mots sémantiquement reliés utilisés dans cette étude produisaient une grande facilitation. Les résultats obtenus infirment un modèle selon lequel des mots en vision parafovéale sont sémantiquement pré-traités.

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Contrary to our phenomenological impressions, when we read our eyes do not move smoothly along the line of text. Rather, we make a series of eye fixations separated by saccadic eye movements. Although there is considerable variability, the average saccade size for skilled readers is about 7-9 letter spaces and the average fixation duration is 200-250 msec (Rayner, 1978). Because of visual suppression during saccades, new information is gained only during the fixations.

The major reason for eye movements during reading is the acuity limitations of the visual system. In order to understand these limitations better, imagine a horizontal line of text projected on the reader's retina as being divided into three regions: fovea, parafovea, and periphery. The fovea is the area of high visual acuity encompassing 2° in the centre of vision, the parafovea extends 5° to the left and to the right of fixation, and the remainder of the line is the periphery. The significance of the distinction between these three areas is that acuity decreases markedly as a stimulus is presented outside of the fovea (Bouma, 1978). Thus, it is necessary to make eye movements to bring words into the fovea for detailed analysis in reading. Given that the fovea encompasses about 2° of visual angle (6-8 letters at a normal viewing distance), it is not surprising that the average saccade in reading is approximately 7-9 letter spaces.

Although the eye movement system is especially attuned to bringing information into the fovea, parafoveal vision also plays an important role in reading. If information to the right of fixation is not available, reading rate decreases sharply (McConkie & Rayner, 1975; Rayner & Bertera, 1979; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; Rayner, Well, Pollatsek, & Bertera, 1982).

The contribution of parafoveal information in reading has fuelled the development of two distinct models. According to the *focussed attention* model (McConkie, 1979; McConkie, Zola, Blanchard, & Wolverton, 1982; Morrison, 1984; Rayner, 1984), reading proceeds by the sequential identification of words in foveal vision. On some fixations, such as when two or three short words fall in foveal vision, more than one word may be identified. Nonfoveal information is important in this model since partial information obtained parafoveally is useful in determining where to look next (McConkie et al., 1982; Rayner, 1984) and/or in helping to identify words on the next fixation (Rayner, 1984). However, according to this model, readers do not obtain semantic information from unidentified parafoveal words.

According to the *semantic preprocessing* model (Bradshaw, 1974; Marcel, 1978; Underwood, 1981), words appearing in parafoveal vision are automatically semantically activated, but without conscious identification. Thus, semantic preprocessing of parafoveal words speeds word identification processes via semantic activation. While the evidence supporting the focussed attention model is based on studies in which subjects are actually reading text, the evidence supporting the semantic preprocessing model is not.

One type of paradigm supporting the semantic preprocessing model involves the simultaneous tachistoscopic presentation of a foveal and parafoveal word. Since the presentation durations in such studies are too brief to allow an eye movement, this situation has been viewed as directly mimicking an eye fixation in reading. There is no guarantee, however, that this static situation really mimics the more dynamic visual processing in reading text. Furthermore, the evidence from this type of paradigm is at best mixed, with some studies (Bradshaw, 1974; Underwood, 1980, 1981) finding evidence for semantic preprocessing, but others (Inhoff, 1982; Inhoff & Rayner, 1980; Paap & Newsome, 1981; Rayner, McConkie, & Zola, 1980; Stanovich & West, 1983) finding little evidence consistent with the model. The second type of paradigm purporting to support semantic preprocessing does not involve parafoveally presented words at all. In this paradigm, a word is presented very briefly in foveal vision immediately followed by a masking pattern that makes it impossible for subjects to indicate reliably if a word was presented prior to the mask. Yet, these "unseen" words affect subjects' responses to a semantically related word which follows after the mask (Balota, 1983; Fowler, Wolford, Slade, & Tassinary, 1981; Marcel, 1983). One implication drawn from these studies (explicitly argued by Marcel, 1978) is that meaning is simultaneously available from a number of places on a page, even though we are consciously aware of only the words we are currently reading. It is worth noting that there is also considerable controversy over the foveal masking studies (see Cheesman & Merikle, 1984; Holender, 1986).

We feel that the semantic preprocessing model can be tested directly in a reading situation. In our experiment, subjects were asked to read sentences as their eye movements were recorded and on-line changes in the text were made at critical locations in the sentences. A typical sentence used in the present study was:

My younger brother has brilliantly
composed a new song for the school play.

In each sentence there was a critical target word location in which alternative words could initially be presented. In the sample sentence, one of three words was initially presented in the sentence: the target word (*song*), a semantically related word (*tune*), or a totally unrelated word (*door*) that was also anomalous in the context of the sentence. In addition, a nonword (*sorp*) that preserved the first two or three letters and overall word shape of the target word could also be initially presented. When the reader's saccade crossed an invisible boundary location in the text (Balota, Pollatsek, & Rayner, 1985; Rayner, 1975), the word initially present in the text was replaced by the target word (song).

The semantic preprocessing model clearly predicts that the parafoveal presence of a semantically related word (tune) in the sentence should facilitate the processing of the target word (song) in comparison to the parafoveal presence of an anomalous word (door). That is, if on fixation *n* the word in the target location receives automatic semantic preprocessing in parafoveal vision, the processing of the target word on fixation $n + 1$ when a semantically related word was present should be faster than when an unrelated word was present. On the other hand, the focussed attention model predicts no difference between the semantically related and unrelated conditions since both involve gross changes in the featural information characteristic of the target word. Both conditions, however, should result in longer processing times than when the visually similar nonword was initially present.

METHOD

Subjects

Twenty-four members of the University of Massachusetts community were paid to participate in the experiment. They all had normal uncorrected vision and half of them had previously been in an eye movement experiment.

Procedure

When a subject arrived for the experiment, a bit bar that eliminated head movements was prepared and calibration of the eye movement equipment took place. Calibration was followed by 10 practice sentences, which in turn were followed by 40 experimental sentences embedded among 60 other sentences. After reading each sentence, subjects pressed a button which terminated the display. Subjects were asked to read for comprehension and were periodically (approximately 10% of the trials) asked to report the sentence they had just read. They were able to report the sentence without difficulty. Subjects were also instructed to report any abnormalities in the display immediately.

Materials and Apparatus

Forty pairs of words were chosen as target words that were semantically related and were of the same length. For each pair, an unrelated word of the same length was also chosen, as was a visually similar nonword. The Appendix lists the target words, the related words, the unrelated words, and the visually similar nonwords. The mean word length of the target word was 5.1 letters. The semantically related pairs were taken for the most part from published word association norms (Palermo & Jenkins, 1964; Postman & Keppel, 1970); others were chosen by intuition. The major constraint in generating the stimuli, given the display change in the study, was that the semantically related words had to be of the same length as the target word. Hence, while some of the pairs were primary associates, some were not.

Sentences were written so that either of the semantically related words could be inserted into the sentence frame quite easily. For example, in the sentence mentioned earlier either song or tune fits into the sentence. Half of the time tune was the target word and the other half of the time song was the target word. Individual subjects saw only one target word (either tune or song). When song was the target word, one of three words could be in the target location when the sentence was initially presented on the CRT: song, tune (semantically related to the target), or door (unrelated and anomalous in the sentence context). Additionally, a nonword (sorp) that was visually similar to the target word could also be presented initially. When the reader's saccade crossed an invisible boundary location, whichever alternative was in the target location was immediately replaced by the target word. Thus, if tune was initially present, when the saccade crossed the boundary it was replaced by song.[1] The boundary location was always the next to last letter in the word to the left of the target word. Thus, in our example sentence, the boundary was the letter *e* in *new*. This boundary location was chosen because only a small percentage of sacades land on the end of words (Rayner, 1979; O'Regan, 1981).

The sentences were presented on two lines of a Hewlett-Packard 1300A CRT with up to 42

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[1] If tune was the target, it could be preceded by tune, song, door, or turc. In either example, if the initially displayed word and the target word were identical (e.g., tune as the initially displayed word and tune as the target), a display change occurred but it was not detectable even to the stationary eye. Nonidentical display changes (song to tune, door to tune, or turc to tune) were easily detected by the stationary eye.

TABLE 1
Gaze Durations (in msec) for Each of the Four Conditions for the Fixated Words

Condition	Word Fixated		
	n − 1	Target	n + 1
Identical (song-song)	251(228)	246(214)	242(213)
Semantically Related (tune-song)	250(228)	286(230)	283(250)
Unrelated (door-song)	251(222)	290(234)	272(245)
Visually Similar Nonword (sorp-song)	248(219)	251(215)	244(211)

Note. The values in parentheses for n − 1 represent the duration of the last fixation prior to crossing the boundary and fixating on the target; for the target word they represent the duration of the first fixation on the target; for n + 1 they represent the duration of the first fixation after fixating on the target. ANOVAs on these measures yielded identical results to those reported in the text for gaze duration.

characters per line. The target word never appeared at the beginning or end of either line. Eye movements were recorded by a SRI Dual Purkinje eye tracker, with a resolution of 10 minutes of arc and linear output over the horizontal visual angle subtended by the sentences. The CRT had a P-31 phosphor, which dropped to 1% of maximum brightness in 0.25 msec. The letters were printed in lowercase (except for the sentence initial letter and proper names). The eyetracker and CRT were interfaced with a Hewlett-Packard 2100 computer that controlled the experiment. The signal from the eyetracker was sampled every millisecond, and eye position was determined every 4 msec. The display change was accomplished in 5 msec. Since the display change occurred during the saccade when vision is suppressed, subjects did not see the change take place.

The subject's eye was 46 cm from the CRT and three characters subtended 1° of visual angle. Eye movements were recorded from the right eye, although viewing was binocular. More details about the apparatus are described by Rayner et al. (1981, 1982).

RESULTS AND DISCUSSION

The primary dependent variable in the study was *gaze duration* on the target word. If only one fixation was made on the target word, that value represented the gaze duration. However, if two or more fixations were made on the target (prior to moving to another word), the fixations were summed. In addition, gaze duration was computed for the word fixated prior to the target word to determine whether subjects were aware of the anomalous word when they were fixating prior to the target word location. Finally, gaze duration on the word fixated following the target word was also examined to determine whether there were any spillover effects from the display change.

The following trials were not included in the gaze duration analyses: (a) sentences in which the eyetracker lost track of the eye (2%), (b) sentences in which subjects reported they saw the display change (less than 1%), (c) sentences in which subjects did not fixate on the target word (5%), and (d) sentences in which the first fixation past the boundary landed on the last two characters of the word prior to the target word (3%). In the latter case the display changed occurred before the target word was fixated. On such trials, since the eye would have crossed the boundary as the saccade ended, there would have been a greater chance that subjects actually saw the display change occur. Indeed, in all cases where subjects reported seeing a display change, the boundary was crossed at the end of the saccade.

A number of clear conclusions emerge from the data which are presented in Table 1. First, on fixations when the target word was fixated there seemed to be no awareness of the presence of the anomalous word, since gaze durations prior to the fixation on the target word did not differ among the conditions ($F < 1$). On the other hand, the stimulus in the target location was apparently identified in the parafovea on a small fraction of the sentences. When either the target word, a visually similar nonword, or a semantically related word was initially present in the sentence, subjects skipped over the target location approximately 7% of the time in each of the conditions, whereas when a anomalous word was initially present they skipped over the target less that 1% of the time. This difference between the anomalous condition and the mean of the others, $t(23) = 7.66, p < .01$, suggests that when the word in the target location was consistent with the rest of the sentence, subjects were sometimes able to identify it parafoveally and hence did not fixate on it. Thus, our argument is that the visually similar nonword was identified as the target word, whereas the semantically related word was identified as itself. Either of these words was consistent with the words that had already been read.

Our major concern, however, is with those sentences in which the word in the target location was fixated and was not identified parafoveally. As implied above, we assume that in most cases when readers fixate the target word, they do so because they have not fully identified it before fixating it. If semantic preprocessing is a major cause of parafoveal benefit in reading, one would expect the semantically related condition to yield shorter gaze durations on the target word than the semantically unrelated condition. As seen in Table 1, this clearly did not happen. An analysis of variance revealed that the main effect of experimental condition was significant, $F(3, 69) = 8.16$, $p < .001$, and post-hoc t-tests revealed that the semantically related and unrelated conditions did not differ from each other ($t < 1$), but both resulted in longer gazes ($p < .01$) on the target word than when no change occurred or when a visually similar nonword was initially present. There was also no effect of the direction of the semantic relationship so that the pattern of effects did not differ when, for example, tune or song was the target. If semantic preprocessing was the reason that parafoveal information is facilitatory, then a preview of a semantically related word in the parafovea should have produced shorter gaze durations on the target word than a preview of a word that was unrelated to the target word.[2] That there was no such effect is damaging evidence against the semantic preprocessing model.

We also examined the gaze duration of the word fixated following the target word (see Table 1). Clearly, the change from one word to another (even though never consciously perceived) spilled over onto the next word fixated, $F(3, 69) =$

[2] Fifty-seven percent of the time, the fixation prior to the target word was on the word just to the left of the target. For those cases where it was not, the target was generally preceded by a very short word. If we included only those data from the 57% of the trials in which the initially displayed word was the next word to the right of fixation, the data pattern was identical to that reported here.

6.38, $p < .01$. However, there was again no effect of changing from a semantically related versus a semantically unrelated parafoveal preview.

To determine if the semantically related words used could produce priming effects, a standard priming study was run with 20 new subjects. A given target (e.g., tune) occurrred only once per subject and was primed by the related word (song) for five subjects and by the unrelated word (door) for five subjects. The remaining 10 subjects received the opposite pairings of the primes and targets (e.g., song-tune) to test if priming occurred in both directions.[3] The primes were presented for 200 msec, and then a 50-msec dark interval was presented before the target in order to mimic the temporal pattern in reading. A pronunciation task was used to avoid problems associated with the lexical decision task (Balota & Chumbley, 1984; Chumbley & Balota, 1984).

An analysis of variance on the pronunciation data yielded a significant main effect of prime relatedness as the related condition (436 msec) was 20 msec faster than the unrelated condition, $F(1, 18) = 14.00, p < .001$.[4] There was no impact of directionality, nor did it interact with prime relatedness (both Fs < 1). Thus, the *set of items used in the reading study produced semantic activation effects in a* standard priming task.

Before concluding that semantic preprocessing cannot facilitate processing in reading, there is one other position that should be considered. Perhaps the parafoveal word's meaning is processed fully enough that the difference in meaning between it and the later fixated word is great enough it causes disruption to the reader, especially when the meaning of the sentence is altered significantly by the change in words. For example, in the sentence

The rabbit was especially slow as it
ran through our vegetable garden.

a change from *slow* to *fast* significantly alters the meaning of the sentence. It is conceivable that disruption caused by such a change might neutralize the facilitative effects of semantic preprocessing.

In order to determine whether such a disruption hypothesis could account for the lack of semantic facilitation observed in the experiment, we analyzed the semantically related pairs to determine the extent to which substitution of one member of the pair for the other markedly changed the meaning of the sentence. We asked 10 subjects (who did not participate in either the reading or priming experiment) to rate the experimental pairs of sentences (which were identical except for the pair of related words) for similarity in meaning. A score of 1 indicated that the meaning of the sentences was identical and 5 indicated that the sentences were drastically different. Of the 40 experimental sentences, only 5

[3] Although the direction of the relationship between pairs of related words was quite arbitrary, it was the same in the priming study as in the reading study.

[4] The reliability across subjects was quite clear: 16 out of 19 subjects showed priming effects with one subject being equal. Also, note that the effects generalize across items and subjects because the error term in the ANOVA included error due to the counterbalancing of items across subjects.

yielded ratings of 3.5 or higher (all were antonym pairs such as *fast-slow*), while 16 of the sentences had a mean rating of 2.0 or lower. To test the disruption hypothesis, we computed the mean gaze duration on the target word for the four experimental conditions for the 20 sentences with the lowest ratings (maximum rating = 2.4, mean rating = 1.6). The pattern of data for these sentences was virtually identical to that presented in Table 1, with the means for the identical, semantically related, unrelated, and visually similar conditions being 240, 288, 286, and 244 msec, respectively. Thus, even with disruption at a minimal level, there was still no difference between semantically related and unrelated words, and therefore the disruption hypothesis is unlikely to explain the lack of a semantic preprocessing effect in the experiment.

CONCLUSIONS

The results of this study showed that changing from one word to another in the target location influenced reading even though the change was not consciously perceived. However, changing from a visually similar nonword to the target caused virtually no disruption. Hence, it was not the display change per se that caused the disruption, but the dissimilarity of the initially displayed stimulus to the target word. Most importantly, changing from a word to a semantically related word was no less disruptive than changing from a word that was totally unrelated to the target word. Thus, in the present reading situation, there was absolutely no facilitation from the presence of a semantically related word. However, when these same words were presented foveally in a standard priming task, the time to name the target word was significantly facilitated by a preceding related word relative to a preceding unrelated word.

All of the results reported here are inconsistent with the semantic preprocessing model. On the other hand, they are perfectly consistent with a focussed attention model and provide evidence that in reading we exert a great deal of selective attention in processing the meaning of words sequentially. More than one word may be identified during an eye fixation, but in such cases the nonfixated word will most often be subsequently skipped over. Thus, the meanings of words that we have not identified do not modulate our reading performance.

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APPENDIX

Target Words and Initially Displayed Previews in the Experiment

1. north-south-phone-norlb
south-north-phone-soulb
2. razor-blade-sweet-razcn
blade-razor-sweet-blabc
3. fast-slow-coin-fanf
slow-fast-coin-sleu
4. doctor-lawyer-orange-donten
lawyer-doctor-orange-lauyon
5. father-mother-circle-fatlon
mother-father-circle-motlon
6. legs-arms-boat-lepz
arms-legs-boat-arnz
7. eyes-nose-seed-eycz
nose-eyes-seed-nocz
8. summer-winter-length-sumnen
winter-summer-length-winlen
9. foot-hand-tone-foaf
hand-foot-tone-haeb
10. navy-army-slap-nauy
army-navy-slap-arny
11. kittens-puppies-offices-kitlems
puppies-kittens-offices-pupgles
12. boots-shoes-times-boolr
shoes-boots-times-shoer
13. bride-groom-paper-bribc
groom-bride-paper-gronn
14. letter-stamps-valley-lethcr
stamps-letter-valley-stangr
15. thread-string-cattle-thriob
string-thread-cattle-stremp
16. ocean-river-catch-oceom
river-ocean-catch-rivcn
17. knife-spoon-metal-knitc
spoon-knife-metal-spoar
18. purse-scarf-favor-purzo
scarf-purse-favor-scast
19. check-wages-sound-cheeh
wages-check-sound-wagcz
20. walk-jump-road-wakl
jump-walk-road-jung
21. daisies-flowers-village-daiercs
flowers-daisies-village-floucns
22. witch-ghost-earth-viteb
ghost-witch-earth-ghozl
23. rattle-bottle-school-ratlhe
bottle-rattle-school-botlhe
24. clock-watch-human-clorh
watch-clock-human-watrk
25. necklace-bracelet-soldiers-nechloec
bracelet-necklace-soldiers-braeolof
26. drink-glass-miles-drirh
glass-drink-miles-glazz
27. warm-cool-nail-wanm
cool-warm-nail-conl
28. silver-copper-health-silucv
copper-silver-health-copgcv
29. ankle-elbow-cream-anktc
elbow-ankle-cream-elbeu
30. tree-bush-plug-trcc
bush-tree-plug-burk
31. priest-bishop-minute-priczl
bishop-priest-minute-bisbog
32. street-avenue-poetry-strccl
avenue-street-poetry-averwc
33. song-tune-door-sorp
tune-song-door-turc
34. beer-wine-rope-becn
wine-beer-rope-wimc
35. winds-rains-horse-winhr
rains-winds-horse-rairr
36. piano-organ-cough-piamc
organ-piano-cough-orgcn
37. lion-bear-heel-licr
bear-lion-heel-beon
38. pole-line-skin-pohc
line-pole-skin-lirc
39. sick-well-band-sieh
well-sick-band-wehh
40. dirt-sand-verb-dinl
sand-dirt-verb-sarb

Note. The first word in each set is the target word, followed in order by the semantically related word, the unrelated word, and the visually similar nonword.