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WORD RECOGNITION PROCESSES IN FOVEAL AND PARAFOVEAL VISION: THE RANGE OF INFLUENCE OF LEXICAL VARIABLES

DAVID A. BALOTA

Department of Psychology
Washington University
Missouri, USA

KEITH RAYNER

Department of Psychology
University of Massachusetts
Massachusetts, USA

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In this chapter, we will review research addressing the influence of lexical variables in foveal and parafoveal vision. Clearly, this topic has relevance to a number of distinct issues in cognitive psychology. First, some of this research is relevant to the long-standing and controversial debate concerning conscious and unconscious semantic processing (see Holender, 1986, and the accompanying commentaries). Second, this research provides important information about how much (and what type of) information an individual can utilize when fixated at a particular location. Obviously, any model of visual word recognition must cope with the constraints imposed by varying levels of information utilization as a function of retinal eccentricity. Third, and most importantly, the utilization of parafoveal information is highly relevant to models of reading. Consider a reader fixated at a particular location in text. The reader has a clear and sharp visual representation for the foveal information, but how much and what types of information can the reader utilize to the right or left of fixation in parafoveal vision? As we will see, there are considerable differences across the different models of reading regarding this issue.

The organization of this chapter is as follows: First, a simple operationalization of the terms "foveal" and "parafoveal" will be presented. Second a brief description of the methods used to address the influence of parafoveal information will be presented. Third, some current views concerning how parafoveal information is used in reading will be discussed, especially noting the different levels of emphasis on parafoveal vs... foveal information. Fourth, research addressing foveal and parafoveal information processing will be reviewed, especially noting the similarities and differences across foveal and parafoveal effects. Fifth, an interactive threshold model of parafoveal information utilization will be outlined. Finally, implications of the reviewed literature for both models of reading and visual attentional mechanisms will be discussed.

I. FOVEA VS. PARAFOVEA: A DEFINITION

In this review, letter spaces falling within the central two degrees of vision will be considered *foveal* information. Letter spaces beyond the foveal region out to five degrees to the left of fixation will be considered *parafoveal* information. Finally, letter spaces outside five degrees from fixation will be referred to as *peripheral* information. In normal reading situations, three or four letter spaces subtend one degree of visual angle (depending upon the size of the print). For the sake of illustration, consider print in which three letters equal one degree of visual angle. In this case, the fovea would include approximately six letter spaces around fixation, with the parafovea including the next twelve letter spaces both to the left and right of the fovea, and finally, the periphory would include any information beyond fifteen letter spaces from fixation.

It is worth noting here that the discrimination among the fovea, parafovea, and periphery is not simply a convenient labelling system referring to distance from central fixation, but rather, is based on the physiological structure of the retina. The relative density of rods and cones varies across these categories (Rayner & Pollatsek, 1989). As expected, one finds a concomitant decrease in acuity across these different categories. This shift in acuity places limits on the degree of parafoveal information utilization, and could potentially influence the strategies a reader might use in dealing with such parafoveal information. For example, because of these acuity limitations, one might ask how much a reader will rely on degraded parafoveal information? We shall now turn to the methods used to address such questions.

II. METHODS OF ANALYSIS

There have been a number of experimental techniques used to investigate the impact of parafoveal information. One approach is to measure a response to a foveal stimulus when a parafoveal stimulus is simultaneously presented (e.g., Bradshaw; 1974: Stanovich & West, 1983a). In most of these experiments, the stimuli are presented so quickly that there is little opportunity for an eye-movement. Although in most cases it is reasonable to assume that the subject is fixated at the appropriate location, it should be noted that such studies typically do not involve eye-tracking systems to insure the actual location of fixation.

The more recent experiments addressing the utilization of parafoveal information have relied upon rather sophisticated eye movement monitoring equipment and a technique known as the *eye-contingent display change* technique. There are a number of variations of this technique, but the basic principle is that, contingent upon the subject's eye-movements, changes are made in the text as the subject is reading. Because we will rely quite heavily on data from such studies, at various points in this chapter, we will briefly describe two of the major variations of this technique that were developed by McConkie and Rayner (1975) and Rayner (1975).

In the *moving window paradigm*, subjects read text on a cathode ray tube (CRT) while their eyes are monitored. Thus, subjects move their eyes as they normally do in reading, but the amount of information available for processing on each fixation is controlled by the experimenter. Within an experimenter defined "window" region, normal text is available for the reader to process. However, the text outside of the window is distorted in some way. For example, all letters outside the window might be replaced by dissimilar letters or by Xs.

When the reader moves from one position in the text to another, the window of available information moves with the eyes. Figure 1 shows an example of a moving window. The question addressed in such studies is the extent to which reading performance decreases as the window size decreases. Obviously, if subjects do not use parafoveal information then one would expect little breakdown in reading performance when parafoveal information is outside the reading window. However, McConkie and Rayner (1975) found with this technique that parafoveal and peripheral information is acquired out to about 15 character spaces to the right of fixation (also see DenBuurman, Boersma, & Gerrissen, 1981; Rayner & Bertera, 1979, Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981).[1]

A second variation of the eye contingent display change technique is the *boundary technique* (Rayner, 1975). In this situation, readers again read text as their eye movements are monitored. However, rather than a display change occurring with each eye movement, only a single display change occurs in association with a given target word location in the text. Figure 1 shows an example of the boundary technique in which a word (or nonword) initially presented in the text is replaced by a target word when the reader's eyes cross over an invisible boundary location. By examining how long a reader fixates on the target word as a function of the relationship between the initially displayed parafoveal word and the target word, inferences can be made about the type of information acquired different distances from fixation.

III. THE PARAFOVEA IN READING: A RANGE OF VIEWS

There are a wide range of views concerning how parafoveal information is used in reading. These range from views emphasizing rather deep meaning analyses of parafoveal information to views emphasizing that the only useful information obtained from parafoveal vision is primarily word-length information. First, on the deep end, there is the view that parafoveal words are semantically preprocessed and that this level of preprocessing influences where and how long a reader will fixate (Hyona, Niemi, & Underwood, 1989; Underwood, 1980, 1981; Underwood, Bloomfield, & Clews, 1988; Underwood, Clews, & Everett, 1989). We should note here that this view is somewhat consistent with a class of "hypothesis testing" or "guessing game" models that place considerable emphasis on anticipating the parafoveal word on the current fixation (Goodman 1967; Haber, 1978; Hochberg, 1970; Levin & Kaplan, 1970, Smith, 1971). According to these models, the reader makes guesses about the parafoveal word based on both partial parafoveal information and the earlier available context. Based on these sources of information, the reader generates a hypothesis about the to-be-fixated word. The reader then moves his/her eyes to the next location, quickly confirms the hypothesis, and begins the process over again by generating a hypothesis about the new parafoveal information. Thus, these models suggest that the reader at some level attempts to identify the parafoveal word before actually fixating on that word. A second view concerning the use of parafoveal information in reading is that super-letter access processes take place parafoveally. In this view, the first syllable or morpheme can be used to initiate lexical access of parafoveal words (Inhoff, 1987). A third

Normal Text

The fluent processing of words during silent reading

13-Character Window (spaces filled)

xxxxxxxxxxxprocessing ofxxxxxxxxxxxxxxxxxxxxxxxxxxx
F

xxxxxxxxxxxxxxxxxxssing of wordxxxxxxxxxxxxxxxxxxxxxxx
F

13-Character Window (spaces preserved)

xxx xxxxxx processing of xxxxx xxxxxx xxxxxx xxxxxxx
F

xxx xxxxxx xxxxxssing of wordx xxxxxx xxxxxx xxxxxxx
F

Boundary Technique

The fluent processing of green during silent reading
F

The fluent processing of words during silent reading
F

Fig. 1. Examples of eye-contingent display techniques used to study the processing of parafoveal information. The top example displays a normal segment of text. The second and third examples display 2 fixations using the moving window paradigm: In this example the window size is 13 character spaces. The fourth example displays the boundary technique. Here, during the reader's saccade, the target word (words) replaces the initially presented stimulus (green). In each of the examples the dot indicates where the eyes are currently fixated.

view is that primarily letter-level information is obtained parafoveally, and this information influences access processes at an abstract letter-code level (Rayner & Pollatsek, 1989). Finally, there is the view that only identified parafoveal word information actually influences reading processes (McConkie, Zola, Blanchard, & Wolverton, 1982). Thus, parafoveal words, unless identified and in most cases directly fixated, have very little impact on reading performance. According to this latter view, parafoveal word length information is used to determine where to look next, but not to aid word identification.

We shall now turn to the empirical data that hopefully helps discriminate between these different approaches. In this discussion, a comparison between foveal and parafoveal priming effects will be made. In each section, the literature concerning foveal effects will be first reviewed, followed by the literature concerning parafoveal effects. The brief description of foveal influences of lexical variables will provide a frame for discussing the impact of such variables in parafoveal vision.

Most of these studies involve various types of priming tasks. The priming paradigm involves the presentation of two stimuli with the subject's task being to respond to one of the stimuli and the relationship between the two stimuli is manipulated. The notion is that if the codes/representations needed for processing the target stimulus are influenced by the prime stimulus, then this should be reflected in changes in performance on the target.

1. Orthographic Priming

It seems safe to assume that orthographic information is somehow used in visual word recognition. However, it turns out that specifying the manner in which orthographic information plays a role in word recognition is not so simple. Moreover, as noted above, there are varying views concerning the influence of orthographic information in parafoveal vision.

1.1. Foveal Studies

Evett and Humphreys (1981) used a four-field masking procedure to address orthographic foveal priming. On each trial, a pattern mask both preceded and followed the presentation of two briefly presented letter strings. The two letter strings varied in terms of orthographic, phonological, or semantic relatedness. Here, we will emphasize the orthographic manipulations. The subjects' task was to identify any of the words that were presented. There are five aspects of Evett and Humphreys' data that are noteworthy. First, subjects were better at identifying the second letter string when it shared letters with the first letter string. Second, this effect apparently occurred because of letter code information instead of simple energy summation because the effect occurred across letter case. That is, the prime letter strings were presented in lower case and the target letter strings were presented in upper case. Third, the authors provided evidence that the similarity in the visual characteristics of the letters (contour and featural overlap) did not appear to modulate the effect. Fourth, the orthographic priming effect occurred when the prime items were nonwords. Thus, the effect did not require lexical-level information. Fifth, the effect was on early visual analyses, apparently subconscious processes, because subjects were very poor at identifying the prime items. Identification of the primes was less than 1.5% across the experiments. Based on these results, Evett and Humphreys argued that the primes automatically activated orthographic abstract letter codes needed for word identification.

Humphreys, Evett, Quinlan, and Besner (1987) have recently replicated the masked orthographic priming effect and eliminated the possibility that the effect was simply due to an increase in errors in the orthographically unrelated condition. That is, it is possible that in the orthographically unrelated condition, subjects were more likely to transpose letters between words. However, an analysis of the error patterns indicated that simple transposition of letters in the unrelated condition could not account for the masked orthographic priming effect. In addition, Humphreys et al. found qualitative differences between orthographic priming when the primes could be identified and when the primes could not be identified. When the primes could be identified, same identity primes (e.g., *lost-LOST*) facilitated identification, compared to both orthographically related (e.g., *list-LOST*) and unrelated (e.g., *tame-LOST*) primes, with no difference between the latter two conditions. However, when the primes could *not* be identified there was clear priming for both identity and orthographically related primes, compared to the unrelated condition, thereby replicating the Evett and Humphreys' (1981) original finding.

Humphreys et al. suggest that because such effects occurred at threshold levels of prime identification, orthographic priming effects involve the early processing of letter strings. Presumably, the primes initiate the production of an abstract orthographic description of the letter string. Primes that are consistent with the target's orthographic description will reinforce that description, whereas, primes that are unrelated will produce different descriptions. Such different orthographic descriptions could have the effect of competing for an orthographic description of the target, thereby lowering target identification.

Before leaving this area, it is important to note our first, and definitely not our last, caveat in the literature. Forster (1987) and Forster and Davies (1984) have failed to find orthographic priming effects from masked primes in a speeded lexical decision task. Thus, when one switches the task from identification to lexical decision performance, it appears that the orthographic priming effect is lost. In this same light, it should be noted that Manso de Zuniga, Quinlan, and Humphreys (1987), have reported orthographic masked priming effects in a pronunciation task. Our preference is to agree with Humphreys et al. that the failure to find the orthographic priming effect in the lexical decision task may be due to the decision component involved in the lexical decision task (e.g., Balota & Chumbley, 1984; Besner, 1983). Finally, our confidence in orthographic priming effects is increased by similar patterns of data in parafoveal priming studies.

1.2. Parafoveal Orthographic Priming

The studies indicating that there are foveal orthographic priming effects when subjects are apparently unaware of the primes might lead one to speculate that there may also be such effects from the parafovea across saccades. In some ways the situation is similar to the masked foveal priming situation. That is, on fixation *n* the reader has parafoveal information available that will come into the fovea on fixation *n* +1. Thus, subjects are receiving a prime from the parafovea for the next fixated target stimulus. Moreover, the saccade between fixations might produce a masking stimulus just as in foveal masked priming studies, reviewed above.

However, there are obvious differences between foveal and parafoveal orthographic priming situations. The major being the retinal location of the stimuli. Humphreys et al. suggest that their effects are due to the construction of an orthographic representation of the stimulus that holds positional information. It is possible that their effects are intimately tied to the translation of retinal positional information to orthographic positional information. If this were the case, then one might not expect parafoveal orthographic priming because the prime on fixation *n* is at a different retinal location than the target on fixation *n* +1.

It is, of course, possible that a more central buffer could integrate visual information across saccades. If this were the case then the importance of retinal location might be less crucial. In fact, some early research on this topic supported the existence of something akin to a purely visual buffer (Jonides, Irwin, & Yantis, 1982; McConkie & Rayner, 1976; Rayner, 1978;). However, although the notion is tantalizing, the more recent research indicates that there is little evidence for such a buffer (Jonides, Irwin, & Yantis, 1983; Irwin, Yantis, & Jonides, 1983; Rayner, McConkie, & Ehrlich, 1978; Rayner, McConkie, & Zola, 1980; Rayner & Pollatsek, 1983). Thus, any influence of parafoveal orthographic information must not be on processes that are tied to a purely visual integrative buffer nor to processes tied to specific retinal locations. In this way, such parafoveal orthographic priming effects may provide important insight into the mechanism(s) underlying the impact of orthographic information.

McConkie and Zola (1979) provided support for the notion that parafoveal orthographic information has an impact on reading performance. In their study, subjects read passages that alternated case across adjacent letters. Furthermore, across fixations, the cases changed from lower to upper case and vice versa. For example, "The cat chased the dog," might be displayed as "ThE cAt ChAsEd ThE dOg." on fixation *n* and "tHe CaT cHaSeD tHe DoG." on fixation *n* +1, and so on. The interesting result was that subjects read as quickly with the characters alternating across fixations as they read when the characters did not switch across fixations. If subjects were using parafoveal information, as the moving window experiments cited earlier clearly suggest, it appears that switching the case of that parafoveal information does not influence reading performance. Thus, these results suggest that the information used from the parafovea is at the abstract letter level, i.e., the parafoveal information is neither tied to visual form nor case.

Research by Rayner et al.(1980) provides some of the clearest evidence of parafoveal orthographic priming. In this research, a word was presented to the subject's parafovea and during the saccade was replaced by a target word that the subject pronounced aloud. Rayner et al. varied the orthographic relationship between the preview string and the to-be-pronounced target. The results indicated that pronunciation latency to the target decreased with increasing orthographic similarity between the preview item and the target. In particular, if the first two or three letters in the initial parafoveal stimulus and the target word were identical, facilitation occurred. It is noteworthy that there was relatively little facilitation when the last two or three letters of the target occurred in the parafoveal preview. The Rayner et al. study also provided evidence that the parafoveal orthographic priming effect depended upon how far into the parafovea the stimuli occurred, i.e., there was more facilitation at 3 degrees than at 5 degrees. Finally, and most importantly, Rayner et al. found that there was as much parafoveal orthographic priming in conditions where the case changed between the parafoveal preview and the target item, compared to conditions where case did not change. Thus, this is a "true" orthographic priming effect that reflects abstract letter code information instead of visually based information.

More recently, Inhoff (1989a) demonstrated that a parafoveal orthographic priming effect can also be produced by letters at the end of a word that provide a parafoveal preview. In this study, Inhoff found that word-initial and word-final trigrams produced parafoveal facilitation when the remaining letters of the word were replaced by Xs. (It is worth noting that the word final previews did produce smaller parafoveal preview effects than the word initial previews in this condition.) However, when the remaining letters were replaced by dissimilar letters, preview benefits were obtained only from conditions where the beginning letters were available in the parafovea. Thus, it appears that word-final letters can produce a parafoveal preview effect when these letters are made distinct by flanking them to the left with Xs. Interestingly, Inhoff also found that the saccades were longer when the whole word preview was available compared to a no preview control condition. Hence, not only does the parafoveal information influence access processes for a lexical representation, such information also can influence the subsequent saccade. We shall return to the relationship between parafoveal information and saccade length below.

It is important to note that there has been some controversy in the literature regarding the parafoveal orthographic priming effect. For example, McConkie, Zola, Blanchard, and Wolverton (1982) reported results that appeared to question the use of parafoveal orthographic information during reading. In this research, short texts were constructed such that four different words could potentially fit within a sentence context. These words differed in their initial and/or fourth letter positions (e.g., *weedy, weepy, seedy, seepy*). In the visually dissimilar condition, two of the words alternated across successive conditions. For example, *weedy* changed to *seepy* and *seepy* changed to *weedy* on successive fixations. The notion is that if subjects use parafoveal information then this alternating condition should produce longer fixations than a control condition in which there were no display changes. Although the alternating conditions did slow single fixations on the target by 12.5 ms, this difference did not reach significance. In addition, McConkie et al. found that subjects' later recognition memory for the words was uninfluenced by the parafoveal information that they received on subsequent fixations and was primarily dependent upon the words that they had actually fixated. Based on this overall pattern of data, McConkie et al. argued that readers only process (in any meaningful fashion) the words they directly fixate.

We feel that there are a number of problems with McConkie et al.'s (1982) acceptance of the null hypothesis. These are elaborated in Balota, Pollatsek, and Rayner (1985) and so we will simply list these concerns here. First, with respect to the episodic recognition memory results, these data are not conclusive because primes can have an impact on word recognition processes without influencing later episodic memory performance (Balota, 1983). Second, the size of the effect in the McConkie et al. study on the single fixation duration data was comparable to a highly significant effect reported by Balota et al. The major difference across these studies is that in the Balota et al. study there was more than 3 times the number of observations reported by McConkie et al. Third, the target stimuli in the McConkie et al. study were relatively low in frequency of occurrence and were relatively unconstrained by the preceding sentence context. As described below, constraint can influence the degree of parafoveal priming. In fact, when viewed in this light, the small effects reported by McConkie et al. could be viewed as more consistent than inconsistent with the research demonstrating parafoveal orthographic priming effects.

2. Contextual Constraint and Stimulus Degradation

Because of acuity limitations, one might consider parafoveal information as similar to degraded foveal information. If this were the case, then it might be useful to compare the research addressing foveal stimulus degradation and its interaction with other variables to the research addressing parafoveal stimulus presentation and its interactions with the same variables. One such variable that has received a considerable amount of attention in both the foveal and parafoveal literature is contextual constraint. The original research involved foveal priming and addressed whether semantic prime relatedness has additive or interactive effects with stimulus degradation. Through the use of Sternberg's (1969) additive factors logic, it was hoped that this research might provide information regarding the stage(s) that the prime context exerted its influence (see Meyer, Schvaneveldt, & Ruddy, 1975). More recently, as described below, similar questions have been asked regarding the impact of context on the utilization of parafoveal information.

2.1 Foveal Priming

The research on single word foveal priming is quite clear. Across a wide variety of tasks and stimulus degradation manipulations, subjects produce larger priming effects when the stimuli are degraded compared to when they are not degraded (e.g., Becker & Killion, 1977; Massaro, Jones, Lipscomb, & Scholz, 1978; Meyer et al., 1975). Although the early research on sentence context effects and degradation produced some inconsistencies (e.g., compare Schuberth, Spoehr, & Lane, 1981, with Stanovich & West, 1979), the more recent research by Stanovich and West (1983b) suggests that the previous failures to find context by degradation interactions were, in part, due to the lack of a strong degradation manipulation. Stanovich and West consistently produced such an interaction in their experiments, and provided information about the underlying nature of the interaction by teasing apart facilitation and inhibition effects. Moreover, Stanovich and West demonstrated that the pattern of facilitation and inhibition effects can be modulated by the type of degradation manipulation (i.e., degradation via the insertion of asterisks between letters vs. degradation via decreases in clarity of the letters). The important point for the present discussion is that there is strong evidence from the foveal priming studies that there are larger context effects for degraded stimuli than nondegraded stimuli.

2.2. *Parafoveal Priming Studies*

Interestingly, the research addressing context and parafoveal priming developed out of a concern with the early Rayner et al. studies on the integration of orthographic information across saccades (e.g., Rayner, 1978; Rayner et al., 1978; 1980). Both McClelland and O'Regan (1981) and Paap and Newsome (1981) pointed out that in the earlier Rayner et al. studies, a rather small set of stimuli were used and these stimuli were repeated within a given experimental session. Thus, it was possible that some of the parafoveal orthographic priming effects may have been due to subjects building up an expectancy that certain stimuli would appear in the parafovea, thereby facilitating their use of that parafoveal information. In fact, both McClelland and O'Regan and Paap and Newsome argued that when subjects have no expectancy regarding the parafoveal information, there is no impact of that information.

First, let us address the possibility that there are no parafoveal orthographic priming effects without constraining context. Although detailed reservations about this argument can be found elsewhere in the literature (e.g., Balota & Rayner, 1983; Rayner & Slowiaczek, 1981), it is sufficient here to simply note three points. First, in a control experiment, Paap and Newsome did not find orthographic priming effects with their stimuli in foveal vision. Therefore, it is unlikely that such effects would be found in the parafovea. Interestingly, the Paap and Newsome study involved a lexical decision task, and therefore, is consistent with our earlier arguments concerning Forster's failure to find orthographic priming effects in foveal lexical decision performance. Second, both McClelland and O'Regan and Paap and Newsome's arguments about no parafoveal priming effects rely on the notion of an appropriate neutral prime condition. Clearly, there are concerns in the literature regarding the nature of a true "neutral baseline" (DE Groot, Thomassen, & Hudson, 1982; Jonides & Mack, 1984; Rayner & Slowiaczek, 1981).

Third, and the most serious difficulty with the argument that context totally modulates the use of parafoveal orthographic information, are the results of a study by Balota and Rayner (1983). In this study, the total pool of target words was increased to 512 in an attempt to minimize the likelihood that subjects could generate an expectancy for the parafoveal items. The results from two experiments indicated that even when no context is provided subjects benefitted considerably from orthographically related previews compared to unrelated previews. Thus, although context may indeed influence the utilization of parafoveal information, the results from Balota and Rayner's study clearly indicate that the availability of related context is not a necessary condition for the utilization of parafoveal information.

Balota and Rayner also addressed whether there are interactive effects between parafoveal orthographic information and contextual constraint, as both McClelland and O'Regan and Paap and Newsome suggested. On each, in the Balota and Rayner study, subjects were presented a foveal word (e.g., *reptile*) along with an initial parafoveal preview item (e.g., *snckks*). The subject's task was to pronounce the parafoveal item as quickly as possible. During the eye-movement to the parafoveal item, the parafoveal preview was replaced by a word that was either (a) semantically related to the foveal word and visually related to the parafoveal preview (e.g., *snakes*), (b) semantically unrelated to the foveal word and visually related to the parafoveal preview (e.g., *sneaks*), (c) semantically related to the foveal word and visually unrelated to the parafoveal preview (e.g., *lizard*), or (d) semantically unrelated to the foveal word and visually unrelated to the parafoveal preview (e.g., *limits*). The results indicated that when subjects only had 250 ms to use the semantic context (Experiment 1), there were additive effects of semantic context and parafoveal preview; however, when subjects were given 1250 ms to use the semantic context (Experiment 2), there were interactive effects of semantic context and parafoveal preview. Thus, when subjects are given sufficient time to generate expectancies concerning the parafoveal preview there are interactive effects between context and parafoveal information. We now have three studies yielding interactive effects of contextual constraint and parafoveal visual information (Balota & Rayner, 1983; McClelland & O'Regan, 1981; Paap & Newsome, 1981).

Balota and Chumbley (1985) attempted to extend the earlier Balota and Rayner (1983) study to determine if additive or interactive effects of contextual constraint and parafoveal orthographic information will be found in a more natural reading situation. Subjects were presented sentences such as: "Since the wedding was today, the baker rushed the wedding ____ to the reception." At the critical target location (as indicated by the underlined area), subjects either received a high-predictable word (cake) or a low-predictable word (pies). This manipulation was factorially crossed with the visual similarity of the parafoveal preview that was presented before the subject fixated on the critical area. This was accomplished via the invisible boundary technique described above. In the present example, the eyes had to cross the letter "n" in wedding before the target was displayed, thereby replacing the initially displayed parafoveal word or letter string. The results yielded two patterns that indicated that contextual constraint influenced the use of parafoveal orthographic information. First, subjects were more likely to skip the target area when the parafoveal preview was visually consistent with the high-predictable word compared to when it was consistent with the low-predictable word. Second, there was a significant interaction between parafoveal preview and predictability in the gaze duration data. (Gaze duration refers to the total time spent fixating the target word before making a saccade to another word.) This interaction indicated that there was a larger parafoveal priming effect for the high-predictable words compared to the low-predictable words, precisely as the earlier studies indicated.

The results reviewed in this section appear to be rather straightforward. Both the foveal and the parafoveal priming studies clearly provide evidence that contextual constraint has different effects on degraded and nondegraded stimulus presentation. Although we will return to this pattern later, it is important to note a potential dilemma. It appears that the interactions are of a different nature in foveal and parafoveal priming studies. In the foveal priming studies, context has a greater impact for degraded stimuli than nondegraded stimuli. In the parafoveal priming studies, context has a greater impact when the parafoveal visual information is in some sense not degraded, i.e., when it is visually consistent with the to-be-fixated target.

One major difference in the foveal and parafoveal priming studies that may help to resolve this dilemma is the subject's response requirements. In the foveal priming studies, subjects are forced to make a response to a degraded stimulus. Thus, any contextual constraint might prove especially helpful in identifying the stimulus. However, in the parafoveal studies, the subjects do not make a direct response to the degraded parafoveal item. For example, in the Balota et al. study, the subjects always received a clear and sharp presentation of the target in 200-250 ms, i.e., when they moved their eyes to the target word. Thus, there was no need to rely on context to "force" a response. In this light, the potential dilemma may be resolved by assuming that in the foveal studies, the target is degraded and subjects use context to help identify the stimulus, whereas, in the parafoveal studies, there is no forced reliance on context (i.e., no need to guess based on partial information) because the parafoveal stimulus will soon receive a very sharp and clear fixation.

Of course, the above discussion does not specify the underlying mechanism(s) producing the context by parafoveal information superadditive interaction. We believe this superadditive interaction is due to lexical-level representations that are receiving top-down information from preceding context along with bottom-up parafoveal orthographic information. The superadditive influence of these two variables suggests both the role of (a) interactive thresholds and (b) interlexical inhibitory processes. With respect to the notion of interactive thresholds, we are simply suggesting that when activation reaches a specific level at a logogen (Morton, 1969), there is a qualitatively different impact on performance. For example, one might assume that there is a level of activation that is sufficient to engage attentional resources. This would be quite consistent with the impact of SOA across the two experiments in the Balota and Rayner (1983) study described above.

With respect to the notion of interlexical inhibitory processes, we are simply suggesting that when a given lexical representation begins to accumulate activation, it will also inhibit the activation of related lexical representations within a given domain. For example, if the word "pastry" is presented as semantic context, then all members of that category will become at least partially activated and serve to mutually inhibit each other. Such a mutual inhibition mechanism might produce a situation where there is little net activation for any given member within the general category. Likewise, with respect to parafoveal activation, a subject may pick up "ca" from the parafovea and this might partially activate many different lexical candidates. However, because "ca" activates many candidates, there is considerable mutual inhibition from these partially activated candidates such that there is relatively little facilitation for any single member that is consistent with "ca". These are examples concerning how partial activation of lexical representations might produce little net facilitation. However, in some cases either contextual constraint or parafoveal information may be sufficient to allow one lexical representation to dominate. For example, if the context specifies a relatively unique response such as *cat* to *dog* then the lexical representation for *cat* may dominate the relatively lower levels of interlexical inhibition produced by other possible candidates. This would produce a net facilitation effect for *cat*. Likewise, with respect to parafoveal activation, if *cak* is available from the parafovea, then this may be sufficient for the lexical representation cake to dominate the inhibition from related neighbors, and therefore, produce facilitation. The important point here is that the scope and strength of the activation pattern is crucial in predicting whether one will find any net facilitation.

This framework nicely accounts for the superadditive effects of context and parafoveal information. First, consider the possibility that on some trials contextual constraint (e.g., pastry), by itself, may not be sufficient to surpass the interactive threshold and influence performance. As noted, although contextual constraint may produce some activation, it may activate a number of consistent logogens, and these may mutually inhibit each other such that there is little net impact on performance. Likewise, on some trails, the influence of parafoveal activation (e.g., *ca*), by itself, may not be sufficient to surpass the interactive threshold. Again, parafoveal information may produce some activation for a number of visually consistent logogens, and these may mutually inhibit each other. However, when both sources of information are available, nearly all trials should produce sufficient activation for a single logogen to surpass the interactive threshold (see Grossberg, 1978; McClelland & O'Regan, 1981, for similar accounts). For example, if *ca* is available from the parafovea and *pastry* is available from context, then this should provide sufficient activation for the logogen representing *cake* to surpass the interactive activation threshold and therefore, dominate the inhibition produced by partially activated representations. It is important to note the importance of the inhibitory mechanism. If there was not an inhibitory mechanism, then it is unclear how one could account for the observed superadditivity. Thus, we believe that this pattern provides important support for the notion of interlexical inhibitory mechanisms. McClelland and Rumelhart (1981) describe a similar phenomenon referred to as the "rich get richer" effect. The important point for the present discussion is that this interactive threshold model nicely accounts for the superadditive interactions between context and parafoveal information reported in the literature.

3. Word-frequency Effects

3.1. Foveal Vision

Across a wide variety of foveal word recognition tasks, high-frequency words produce better performance than low-frequency words (e.g., Becker, 1979; Broadbent, 1967; Frederiksen & Kroll, 1976; Rayner & Duffy, 1986; Whaley, 1978). Although there has been considerable discussion about both the underlying theoretical account of the frequency effect (e.g., Becker, 1979; 1980; Morton, 1969; 1982, Forster, 1976, 1979) and the particular loci of the effect across the various tasks (e.g., Balota & Chumbley, 1984, 1985; Catlin, 1969, 1973; Chumbley & Balota, 1984; Kliegl, Olson & Davidson, 1982, 1983; McCann & Besner, 1987; Theios & Muise, 1977), we are unaware of any researcher who has argued that word-frequency has *no* impact on foveal word recognition. Thus, we state with confidence that word-frequency does indeed have some impact on foveal word recognition. The more intriguing question is whether it also has an impact in parafoveal vision.

3.2. Parafoveal Vision

Inhoff and Rayner (1986) reported a study which appears to indicate that frequency can modulate the impact of parafoveal information. This study involved the moving window technique described above. As a reminder, this procedure involves a window of that moves with the reader's eyes to expose new information on each fixation. Inhoff and Rayner manipulated how much information was available to the right of fixation. (Across these conditions, all letters to the left of fixation were always available.) The three different window conditions were: (a) a one-word condition, in which there was no information available to the right of the fixated word; (b) a two-word condition, in which the currently fixated word and the word immediately to its right were available; and (c) a full-line condition, in which all characters on the line were available. In addition to these preview conditions, Inhoff and Rayner manipulated the word frequency of a given word in the sentence frame. These words were equated on length and contextual predictability.

The results of the first fixation duration data on the target word indicated that frequency had no impact in the one-word window condition, but did have a substantial impact in the two-word and the full-line window conditions. This appears to indicate that part of the impact of the parafoveal preview is on early processes that are reflected in the first fixation duration data. Moreover, such early processes are sensitive to word frequency. These results could again be viewed as consistent with the interactive threshold model described above. If high-frequency words have lower thresholds than low-frequency words then the interactive threshold should be more likely to be surpassed with a high-frequency preview than a low-frequency preview[2].

4. Within-Word Lexical Constraints

There have been a number of studies indicating that the letters at the beginning of a word play an especially important role in word recognition. This special status of word initial information is quite consistent with models of lexical access developed by Marslen-Wilson and Welsh (1978), Taft and Forster (1976), and Taft (1979). Although the Marslen-Wilson and Welsh model was developed primarily to account for auditory word recognition, it serves to highlight the potential importance of word initial information. Basically, the suggestion is that in speech perception the initial few phonemes of an input word activate a cohort set in the lexicon. This set contains a representation for all words that begin with the phonemes that are currently available. As more of the stimulus unfolds, the cohort set is reduced until there remains only one candidate in the set. Presumably, for some words, recognition occurs before the full word is presented, i.e., at the point at which there are no longer any potential candidates (Marslen-Wilson & Tyler, 1980; Marslen-Wilson & Welsh, 1978). One might expect similar effects in visual word recognition. That is, the earlier a letter sequence produces a unique candidate, the earlier recognition will occur. Moreover, because, as the above literature indicates, beginning word information appears to be available in the parafovea, one might expect similar effects in parafoveal vision.

4.1. Foveal Information

Experiments by Lima and Pollatsek (1983) and Mewhort and Beal (1977) indicate that word-initial information plays a special role in word recognition. In both studies it was found that delaying presentation of the final segment of a word produced less interference than delaying presentation of the beginning segment of a word.

A study by Lima and Inhoff (1985) provides evidence concerning "how" word-initial information plays a role in word recognition. Within the cohort framework, they suggested that word-initial information may influence word recognition processes via within-word lexical constraints. In order to address this, they presented target words embedded in sentence contexts that varied in the degree of constraint provided by the first three letters of the words. For example, consider the words *dwarf* and *clown*. The word *dwarf* is a high-constraint item because the first three letters *dwa* produce very few alternative strings, whereas *clown* is a low-constraint item because the first three letters *clo* produce many possible candidates, e.g., *clone, close, cloud, clods*. The predictions were quite clear. If constraint influences lexical access in a left-to-right fashion then one would expect fixations on the high-constraint words to be shorter than on the low-constraint words. That is, the recognition point in *dwarf* is earlier than the recognition point in *clown*. The results provided no support for this prediction. In fact, the high-constraint words led to longer fixations than the low-constraint words, precisely opposite to the constraint hypothesis. Thus, the special status of word initial information does not appear to be at the level of lexical constraint, at least in the fovea.

4.2. Lexical Constraint and Parafoveal Information

In addition to addressing the influence of constraint on foveal processing, Lima and Inhoff also looked at the influence of constraint on parafoveal processing. As described earlier, Rayner and his colleagues have demonstrated that subjects are especially sensitive to the beginning letters of parafoveal previews. Thus, it is possible that subjects might use the constraint imposed by these parafoveal letters to influence the speed of access for a parafoveal word when it is eventually fixated. Lima and Inhoff again relied on the moving window technique to test this possibility. Like Inhoff and Rayner (1980), they used the one-word window condition, the two-word window condition, and the full-line condition. The notion is that only in the two-word and full-line condition will parafoveal information be available for the high- and low-constraint words. Thus, one might expect an interaction between constraint and window size with the high-constraint words being especially facilitated by the parafoveal preview. The results yielded additive effects of constraint and window size. Thus, there was no evidence that lexical access was initiated in the parafovea on the basis of the degree of lexical constraint provided by the word-initial sequence. This basic pattern was replicated in a second experiment with a slightly different window size manipulation.

We should reiterate here that within-word constraint did not simply fail to produce an effect in foveal vision, but it actually produced a significant effect that was opposite to the constraint hypothesis. Lima and Inhoff suggested that subjects spent less time on the low-constraint items than on the high-constraint items because the word initial trigrams in the low-constraint items were more "familiar" to the subjects. Thus, the effect of constraint was simply an effect of familiarity. However, this influence of familiarity only occurred when the words were directly fixated and did not occur parafoveally, i.e., there was no evidence of an interaction between constraint and window size. This is an interesting finding when compared with the Inhoff and Rayner results described above. That is, Inhoff and Rayner found that frequency (a strong correlate of familiarity) modulated parafoveal utilization. Possibly, the degree of familiarity produced by the word initial trigrams in the Lima and Inhoff study was not sufficient to influence parafoveal processing. In support of this, it is noteworthy that the main effect of constraint in the Lima and Inhoff study was rather small, 10-16 ms, compared to the rather large main effect of frequency in the Inhoff and Rayner study, 30-40 ms. In fact, according to the interactive threshold model, one might not expect variables that produce small main effects in foveal vision to produce significant interactions when crossed with parafoveal preview.

5. Access Codes and Prefix Stripping

There has been considerable discussion in the literature concerning the access codes in word recognition. For example, Taft and Forster (1975) suggested that subjects use morphological access codes, which necessitates partitioning a word into its corresponding morphemes prior to lexical access. On the other hand, Spoehr and Smith (1973, 1975) argued that syllables may be the major access code. Finally, Taft's (1979) Basic Orthographic Syllabic Structure (BOSS) emphasizes both syllabic and morphemic information in parsing a word into its access code.

The present section addresses foveal and parafoveal access codes. Again, because there is evidence for the use of word initial information in the parafovea, it is possible that subjects may use this word initial information as an access code for word recognition.

5.1. Foveal Vision

There has been considerable evidence supporting the notion of morphemic access codes in foveal word recognition (e.g., Lima, 1987; Lima & Pollatsek, 1983; Snodgrass & Jarvella, 1972; Taft, 1979, 1981; Taft & Forster, 1975). Consider, for example, the Taft (1981) study. Taft reported evidence from both lexical decision and pronunciation tasks that prefixed words (e.g., *remind*) were responded to more quickly than pseudoprefixed words (e.g., *relish*). This finding provides support for the notion of "prefix stripping." That is, in recognizing a word, subjects first attempt to strip any common prefixes from that string to determine the base morpheme used for lexical access. Because subjects should inappropriately strip the prefix from pseudoprefixed words, this should force them to reach a "dead-end" after the prefix is stripped and then go back and use the non-stripped version of the word as the access code. Thus, subjects should be slower for pseudoprefixed words than prefixed words, precisely as Taft reported. Lima (1987) has recently replicated this basic pattern in a more natural reading situation.

5.2. *Parafoveal Vision*

As suggested above, it is possible that subjects use the beginning letters of parafoveal words to help identify the beginning morpheme of the to-be-fixated word. Lima (1987) conducted a study that addressed this possibility. In Lima's experiment, subjects were presented either pseudoprefixed (e.g., *relish*) or prefixed (e.g., *remind*) words in a critical location within a sentence. Lima used the boundary technique described above. She manipulated the type of parafoveal information that was available to subjects before their eyes crossed a critical boundary prior to the critical word location. For example, the reader might receive the letters common to the two words along with random letters or x's (e.g., *rensbl* or *rexxxx*) before crossing the critical boundary. This condition provides the reader with consistent parafoveal information concerning the prefix. In the control conditions subjects might parafoveally receive random letters or all x's (e.g., *kmnsbl* or *xxxxxx*). When the eyes crossed the critical boundary location, the stimuli changed to either the word *relish* or *remind*. Lima found a main effect of prefixed vs. pseudoprefixed words and a main effect of parafoveal preview on fixation duration. However, there was no evidence of an interaction between these two variables in either of two experiments.

As Lima points out, if the model of prefix stripping is simply that the primary route for lexical access necessitates prefix stripping, then the additive effects of preview and prefixed vs. pseudoprefixed words is not damaging. That is, readers could have begun prefix stripping for both prefixed and pseudoprefixed words in the parafovea. On the other hand, Lima points out that it is possible that words can be accessed through two routes. One route is based on the prefix-stripped morpheme while a second route is based on the whole word. This model would involve a race between these two routes, with lexical access involving the first completed. Lima suggests that this model predicts parafoveal preview will interact with the prefix manipulation. That is, for the pseudoprefixed word, the preview should disrupt performance via the prefix-stripping route, whereas, the preview should facilitate performance via the whole word access route. However for the prefixed word, both access routes should benefit from a parafoveal preview. That is, the preview should benefit access via the prefix stripping route and the whole word access route. Thus, there should be a larger preview effect for prefixed words than pseudoprefixed words. The results provided no evidence for such an interaction. Thus, although Lima's data cannot dismiss a model of parafoveal processing that assumes a primary prefix-stripped access route, her data are difficult to accomodate within a model of parafoveal processing that assumes both a prefix-stripped and a whole word access route. Finally, it should again be noted that the size of the main effect was quite small in this study, and therefore, based on the interactive threshold model, one might not expect an interaction.

6. Semantic Parafoveal Processing

One of the more seductive notions in the literature on parafoveal processing, is that readers can analyze meaning from words available in the parafovea. In fact, as noted in the beginning of this chapter, some models of reading (e.g., Goodman, 1967; Hochberg, 1970; Neisser, 1967; Smith, 1971) suggest that readers combine contextual information with parafoveal information to make guesses about the parafoveal word. Fixations on a given area are primarily for confirming earlier semantic preprocessing. It should be noted that we are using the term semantic preprocessing here to indicate that subjects have not consiously attended to the parafoveal item. If subjects have time to attend or consciously process the parafoveal item, we have no reason to doubt that one will find semantic effects.

There are a number of reasons why one might expect parafoveal semantic preprocessing effects. First, consider how pictures are processed. It appears that when one looks at a picture, the eyes move very quickly to regions that are judged to be informative (e.g., Antes, 1974; Mackworth & Morandi, 1967). This would appear to suggest that parafoveal processes guide the eyes to the most informative region. However, as Rayner and Pollatsek (1989) have argued, this finding in picture processing may not be relevant to reading because pictures provide many more cues than print regarding informative areas. When one considers print, there is very little in the way of informative areas that stand out on a page of normal text.

The research on foveal threshold priming could also be viewed as supporting the possibility of parafoveal semantic preprocessing (Balota, 1983; Evett & Humphreys, 1981; Fowler, Wolford, Slade, & Tassinary, 1981; Marcel, 1983). This research suggests that stimuli presented very briefly and pattern masked (presumably "unconscious") appear to produce meaning-level analyses. If briefly presented degraded stimuli can access meaning-level analyses in the fovea then why couldn't parafoveally presented stimuli access the same meaning-level analyses?

There are clear differences between foveal pattern masked primes and parafoveal word information. In the foveal masking situation, the primes are presented very briefly and followed by patterned masks. In the reading situation the parafoveal primes are available considerably longer and receive lateral masking. Accounts of foveal masking suggest that the pattern mask interrupts the visual codes necessary for conscious awareness of the prime (Marcel, 1983). In fact, if the prime was not pattern masked, subjects could identify the prime items. This contrasts with the parafoveal processing situation. The major limitation of processing parafoveal primes is the visual acuity breakdown in the parafovea, not the mask preventing conscious awareness. Finally, in the typical masked foveal priming paradigm, attention is directed to the same spatial location of the prime, whereas, in the typical parafoveal priming situation, attention is directed away from the spatial location of the parafoveal prime.

6.1. Foveal Priming Studies

When both the context and target are consciously available to the subject in the fovea, associative relatedness facilitates word recognition processes. Such effects have been reported in numerous studies involving lexical decision (e.g., Meyer & Schvaneveldt, 1971; Neely, 1977), pronunciation (Balota & Lorch, 1986; Stanovich & West, 1983b), and threshold identification (e.g., Morton, 1964; Tulving & Gold, 1963). In addition, such effects have also been reported in more natural reading situations. That is, gaze duration on a given target word is influenced by the predictability of that target word based on the preceding sentential context (Balota et al., 1985; Carroll & Slowiaczek, 1986; Ehrlich & Rayner, 1981; Schustack, Ehrlich, & Rayner, 1987; Zola, 1984).

Although the results are quite clear when subjects have time to consciously process the prime information, there is some debate concerning such priming effects when the primes are masked below a conscious identification threshold. The impact of such subthreshold stimuli has produced a long-standing debate in psychology. The focus of the debate in the masked-priming literature is whether the prime stimuli are truly presented below the subjects' conscious threshold (see Holender, 1986, and the accompanying commentary on this issue).

As we shall see the issue of objectively defined subthreshold presentation is also critical in our evaluation of the parafoveal priming literature. If true "semantic preprocessing" of parafoveal items occurs then this implies that the subjects were not consciously aware of such items. If subjects were aware of such parafoveal items, then it is not surprising that such items have an impact on performance.

6.2. Parafoveal Priming

We will begin our discussion of this literature with an often-cited study by Bradshaw (1974). In this study, subjects were presented three letter strings centered horizontally at fixation. The foveal word was always a homograph (e.g., *bank*). The two parafoveal strings included a disambiguating word (e.g., *river*) and a nonsense string of consonants (e.g., *spcrnf*). Across trials, the two parafoveal items randomly alternated between the left and right adjacent sides of the foveally presented homograph. The three-word displays were presented for 125 ms, after which subjects made a forced-choice decision between two words related to the two different meanings of the homograph. Finally, subjects wrote down all they had seen on a given trial. The results indicated that on trials in which subjects could not identify the parafoveal disambiguating stimulus, it still had an impact on the interpretation of the homograph. (Although this effect was significant, it was quite small, 53% vs. 47%). Thus, the Bradshaw results do support the notion of parafoveal semantic preprocessing.

Inhoff (Inhoff, 1982; Inhoff & Rayner, 1980) has conducted research to further address this effect. First, Inhoff and Rayner attempted to replicate the pattern of data reported by Bradshaw. They monitored eye movements and presented the disambiguating stimulus at six different parafoveal locations (one, three, or five degrees to the left or right of fixation). Inhoff and Rayner found no evidence for semantic preprocessing. That is, the results of the forced-choice test could be completely accounted for by two factors: identification of the parafoveal word and chance guessing of the biased meaning. Inhoff (1982) subsequently reported three experiments that extended and replicated the earlier Inhoff and Rayner results. Again, Inhoff found no influence of a parafoveal word on the interpretation of a foveal word above and beyond the probability of (a) correctly identifying the parafoveal word and (b) guessing the biased meaning.

The above results clearly indicate that the conscious choice of an interpretation of a foveally presented word does not appear to be modulated by parafoveal semantic preprocessing. However, it is still possible that a semantically related parafoveal item could influence the speed of recognizing a foveally presented item. In fact, Balota (1983) demonstrated that in a foveal priming situation, a masked prime could influence the speed of recognizing a target homograph but did not influence the conscious interpretation of that homograph. Thus, although the Inhoff research rather conclusively dispels the impact of parafoveal semantic preprocessing on the conscious interpretation of foveal information, it does not eliminate all possible aspects of parafoveal semantic preprocessing.

In fact, the research of Underwood and his colleagues (Underwood, 1976, 1977, 1980, 1981; Underwood, Rusted, & Thwaites, 1983; Underwood & Thwaites, 1982) appears to indicate that parafoveal information has a semantic influence on "speeded" performance. Underwood's research is intriguing because he has reported parafoveal semantic preprocessing across a wide variety of tasks including lexical decisions, category naming, picture naming, and paired-associate naming. Consider, for example, the results reported by Underwood and Thwaites (1982). In this study, subjects made lexical decisions about a centrally located letter string. On each trial a fixation dot was presented, along with a preexposure masked field in the parafovea; after which the foveal and parafoveal strings were presented simultaneously for 50 ms. Following this presentation, the parafoveal masking stimulus was again presented. The results of this study indicated that response latency to the centrally located target (e.g., *rubbish*) was significantly slower when a semantically related word appeared in the parafovea (e.g., *waste*) compared to when a semantically unrelated word appeared in the parafovea (e.g., *bear*). Moreover, there was also significant inhibition when an unrelated homophone (e.g., *waist*) was presented in the parafovea. This basic pattern was replicated in a second experiment. Thus, Underwood and Thwaites argued that their results support the notion of unattended parafoveal semantic and phonological processing.

Underwood's research is clearly provocative. However, we have a number of concerns that diminish our confidence in accepting it as strong support for semantic parafoveal preprocessing. First, Underwood has reported facilitation in some experiments and inhibition in other experiments (e.g., compare

Underwood, 1980, with Underwood, 1981). This difference in pattern of results may eventually be quite important, but currently, there is some debate regarding the underlying cause of the opposite patterns of effects (see Holender, 1986; Underwood, 1986). Second, in none of the experiments were subject's eyes monitored to determine whether they were truly looking at a fixation stimulus. This is particularly problematic in the Underwood and Thwaites study. In this study, the parafoveal cue was always presented to the right of fixation. It is possible that subjects might look slightly to the right of fixation toward the parafoveal stimulus. Of course, one might ask why would subjects look away from the centrally located lexical decision stimulus? It is possible that the presentation of two stimuli might produce a slight bias in the direction of the middle of the two stimuli. If this were the case then subjects may have processed more of the parafoveal stimulus than expected. Third, in none of the studies, were subject's thresholds individually set. Most typically, subjects were informally asked at the end of the experiment whether they recognized any of the words. Clearly, for a brief period of time it is possible that subjects could identify the parafoveal stimulus but by the end of the session, they may be unwilling to guess about the identity of such stimuli, because they no longer remembered these fleeting perceptual experiences. Fourth, even if one finds clear evidence of parafoveal semantic preprocessing in the type of tasks used by Underwood, it is unclear whether such effects truly reflect semantic *pre*processing. For example, consider the possibility that subjects pick up partial information from the parafoveal stimulus but not sufficient information to analyze it for meaning. However, when the foveal item is presented it provides a context to interpret the partial parafoveal information. In fact, this interpretation of the parafoveal item could account for the inhibition effects found in the lexical decision task. That is, on related trials subjects may have sufficient context and parafoveal information to recognize the parafoveal item, and the recognition of that item may distract the subject from the main task of making a lexical decision. On unrelated trials, the context provided by the foveal stimulus should not allow subjects to recognize the parafoveal stimulus based on partial information, thereby not distracting the subject from the lexical decision task. This, of course, would not be true semantic parafoveal preprocessing because subjects would not be able to extract meaning from the partial parafoveal information without the foveal contextual information.

There are two further issues that should be noted here. First, the notion of parafoveal semantic preprocessing is in conflict with the research indicating that within-word constraints (e.g., orthographic and morphological constraints) do not influence parafoveal access processes. If within-word constraints have no impact on parafoveal access processes, then it is unclear how semantic information would play a role in parafoveal processing. It would seem that such within-word access processes in the parafovea should precede any whole-word semantic preprocessing.[3]

Our major concern about the notion of parafoveal semantic preprocessing is that there have been repeated failures to produce evidence for such preprocessing in speeded performance. Consider the results from four separate sets of studies. First, Paap and Newsome (1981, Experiment 2) found no impact of a semantically related parafoveal stimulus on lexical decisions to a foveally presented word. In their third experiment, subjects were required to attend to the parafoveal item by making a lexical decision to that item before they made a lexical decision to the foveal item. Interestingly, the results of the foveal lexical decision task in this situation yielded significant inhibition from semantically related parafoveal items compared to unrelated parafoveal items. This finding is consistent with Underwood and Thwaites observation of inhibition in lexical decision performance from semantically related parafoveal items, described above. The important point to note here is that Paap and Newsome found evidence for such inhibition only when subjects were forced to attend to the parafoveal item. This supports the contention that the parafoveal inhibition effects reported in the Underwood and Thwaites study may not be due to "unattended" processing of the parafoveal items.

Second, Stanovich and West (1983a) failed to find evidence for parafoveal semantic preprocessing. They reported three experiments in which subjects pronounced a given target word that was preceded either by congruous, incongruous, or neutral sentence contexts. In addition, when the target word was presented, it was accompanied by either a parafoveal related modifier noun that was consistent with the continuation of the sentence context or a parafoveal nonword anagram. The results of the three experiments were quite clear. Subjects were faster to name the target word when it followed a congruous context than when it followed an incongruous context (Experiment 1) or a neutral context (Experiments 2 and 3). More importantly, there was no evidence of an impact of the parafoveally presented stimulus.

Third, in a study by Rayner et al. (1980) subjects were initially presented a stimulus word (e.g., *chair*) in the parafovea. During the eye movement to the word, it was replaced by a semantically related target word (e.g., *table*). Rayner et al. found no facilitation in naming the associatively related target word, compared to a visually matched unrelated parafoveal preview word (e.g., chore).

Finally, Rayner, Balota, and Pollatsek (1986) had subjects read sentences that included a critical target word. The invisible boundary technique described previously was used in this study. These researchers manipulated the parafoveal information available before the subject fixated on the target word. For example, if the target word was *song* then the preview was either (a) the identical word *song*, (b) a related word *tune*, (c) an unrelated word *hall*, or (d) a visually related nonword *sorp*. The results were quite clear. The visually similar preview facilitated processing almost as much as the identical preview. More importantly, there was no difference between the related and unrelated preview conditions. Finally, a control experiment yielded a highly significant effect of semantic relatedness for these very same related stimuli (e.g., *tune-song*) when they were foveally presented in a simple pronunciation task. Thus, although these items produced foveal semantic priming, there was no evidence of parafoveal semantic preprocessing in a relatively natural reading situation.

In sum, we have tried to provide a fair appraisal of the research on semantic *pre*processing in the parafovea. Overall, we believe that the best conclusion at present is that there is very little, if any, semantic parafoveal *pre*processing. When such effects are reported, it is simply unclear whether subjects have identified the parafoveal words. If the parafoveal words were identified, then the results simply indicate that there is an effect of a semantic relationship between two visually presented words.

Before leaving this section, we should note that Underwood and colleagues (Hyona et al., 1989; Underwood, Bloomfield & Clews, 1988; Underwood, Clews, & Everett, 1989) have recently reported some studies which are consistent with a version of semantic preprocessing that differs somewhat from our portrayal of such a view. In this section, we have discussed semantic *pre*processing of parafoveal words according to the view that is such words are *pre*processed, the amount of time necessary to identify them in reading when directly fixated should be reduced (as per our discussion of the Rayner et al., 1986, study.) We also discussed semantic *pre*processing wherein processing of a parafoveal word influences the processing of a foveal word. In both of these situations, we have argued that there is little evidence for semantic *pre*processing. In the recent studies by Underwood, readers' eye movements were found to be influenced by the characteristics of parafoveal words. In the experiments, subjects read sentences containing long target words that were informative either at the beginning or the end of the word. A word such as *relocation* is informative at the beginning and redundant at the ending. In other words, if given *ation* subjects cannot determine the identity of the word, but given *reloc* they can. A word such as *intermarry* is redundant at the beginning and informative at the end. Underwood and colleagues have found that readers' eye movements are pulled further into words when the informative part of the word is at the end.

While this finding is consistent with a semantic *pre*processing view, there are some issues that need to be addressed. First, this finding conflicts with a large body of data (see Rayner & Pollatsek, 1987) which indicates that how far the eyes move is largely determined by word length information from parafoveal vision. Second, as Hyona et al. (1989) acknowledge, the effect is quite small and is within the noise level of their eye-tracking system. Third, and more critically, Underwood and colleagues have not provided an account concerning the mechanism by which such preprocessing would work. Of course, these results may simply indicate that letter string information can produce familiarity values in the parafovea that are available to conscious the processing system that guides the eyes to the next fixation. Thus, until further evidence is available on the issue, we will continue to accept the position that semantic preprocessing does not occur in reading.

IV. GENERAL DISCUSSION

The review of the available literature suggests the following: (a) Orthographic letter code information is utilized both foveally and parafoveally. (b) The utilization of such parafoveal information can be modulated by contextual constraints, but is not totally dependent upon contextual constraints. (c) Word frequency influences both foveal and parafoveal access processes. (d) Within-word orthographic constraints influence foveal access processes, but do not influence parafoveal access processes. (e) Within-word morphological constraints influence foveal access processes, but do not influence parafoveal access processes. (f) If true semantic preprocessing occurs, it appears to be restricted to foveal presentations, and there is little in the way of compelling evidence to suggest that true semantic parafoveal preprocessing occurs; when such effects do emerge, the results may really be due to subjects identifying the parafoveal stimulus. We shall now turn to the implications of these data.

1. Superadditive Interactions

One intriguing finding in this literature is that contextual constraint appears to modulate the use of parafoveal information (Balota & Chumbley, 1985; Balota & Rayner, 1983; McClelland & O'Regan, 1981; Paap & Newsome, 1981). There are greater influences of parafoveal information when context constrains that information. As described earlier, one way of interpreting this pattern of superadditivity is to assume an interactive activation model (Balota & Chumbley, 1985; Balota & Rayner, 1983; McClelland & O'Regan, 1981). Within this framework, we have relied on both the notion of lexical thresholds and within-lexical inhibitory processes. These theoretical mechanisms are especially important when one considers massively parallel processing systems and response latency data. Such systems must deal with multiple sources of activation and continuously varying levels of activation. The notions of interactive thresholds and within-level inhibitory processes provide a useful selection heuristic that minimizes the impact of relatively low-levels of activation on performance (also see Balota, Boland, & Shields, 1989; Reder, 1983).

The notion of interactive thresholds handles other aspects of the data in this area. For example, one might account for the Inhoff and Rayner (1986) results indicating that word frequency modulates the size of the parafoveal preview effect by assuming that high-frequency words have lower thresholds than low-frequency words. Obviously this is not a novel approach to word frequency effects (Morton, 1969). It is also possible that the lack of an effect of within-word constraints on parafoveal information utilization may be due to the fact that such constraints produce relatively small effects even in foveal vision. Thus, it is possible that the utilization of such information in the parafovea is not sufficient to avoid the within-level inhibitory effects.

There are further aspects of eye-movement data that support the notion of interactive thresholds. For example, Balota and Chumbley (1985), Ehrlich and Rayner (1981), and Schustack, Ehrlich, and Rayner (1987) have all reported that subjects are more likely to skip over a highly constrained target word than a less constrained target word. This might suggest that in these situations sufficient parafoveal and foveal information combined to surpass the identification threshold. In addition, Pollatsek, Rayner, and Balota (1986) and Inhoff and Rayner (1986) have provided evidence that parafoveal information can sometimes influence the decision *when* to move the eye but not the decision *where* to move the eye. Interestingly, this latter finding suggests that there may be multiple thresholds in the system that influence different decisions in the eye-movement control system (see Rayner & Balota, 1989; Rayner & Pollatsek, 1987).

It is important to note here that we are unaware of other interactive effects in the word recognition literature that are similar in nature to the context by parafoveal information interaction. That is, most interactions are of the nature that the level of Factor A that produces the *slowest* response latency also produces the *largest* impact of Factor B. For example, this is the case for the interactions between (a) word frequency and context (Becker, 1979), (b) degradation and context (Becker & Killion, 1977), (c) developmental stage and context (Stanovich, West, & Freeman, 1981), (d) context and word difficulty (Stanovich & West, 1983b), (e) context and pronounceability of nonwords (Shulman & Davison, 1977), and (f) repetition and frequency (Scarborough, Cortese, & Scarborough, 1977; Scarborough, Gerard, & Cortese, 1979). Moreover, one also finds a similar type of interaction in experiments addressing task (lexical decision vs. pronunciation) by variable interactions (e.g., Balota & Chumbley, 1984; Chumbley & Balota, 1984; Lorch, Balota, & Stamm, 1986; Seidenberg, Waters, Sanders, & Langer, 1984; West & Stanovich, 1982). It should be noted here that these types of interactions are especially susceptible to scaling problems. A 40 ms effect of a variable is approximately the same percentage effect when the subject's overall response latency is 700 ms as a 28 ms effect when the subject's overall response latency is 500 ms. Thus, the interactive effects of contextual constraint and parafoveal information are quite provocative because (a) they provide relatively novel evidence regarding a type of superadditive interactive effect, and (b) they are less susceptible to scaling problems.

2. The Impact of Attentional Demands on Parafoveal Utilization

The utilization of parafoveal information may not only be limited by the acuity of the visual system but may also be intimately tied to the demands placed on the individual's basic cognitive resources. This would be consistent with Mackworth's (1965) classic notion of tunnel vision. Tunnel vision refers to the phenomenon that the useful visual field shrinks when there is a heavy load placed on the central processing system. For example, Williams (1982) has reported evidence that the detection of a parafoveal stimulus is dependent upon the cognitive demands of a foveal task. When foveal task demands are great the utilization of the parafoveal information decreases in a tunnel-vision type fashion. Thus, parafoveal processing is not a constant but may vary with foveal load.

Henderson and Ferreira (1987) have recently reported a study that provides support for tunnel vision in a more natural reading situation. They manipulated foveal difficulty by either varying a lexical variable (word frequency) or a syntactic variable (forcing syntactic reanalysis). This experiment utilized the boundary technique. On fixation *n* subjects received either visually consistent or inconsistent information with the word they would fixate on fixation *n* +1. The important question was whether the impact of parafoveal information would be modulated by the difficulty the reader was having on the currently fixated word. The results indicated that there was a significant parafoveal preview effect when subjects had a relatively easy time in processing the word on fixation *n* (i.e., high-frequency words or words that did not force syntactic reanalysis of the earlier portions of the sentence); however, when the currently fixated word was relatively difficult (i.e., low-frequency words or words that forced syntactic reanalysis), there was a relatively smaller parafoveal preview effect. This is quite consistent with the notion of tunnel vision. When subjects had difficulty on fixation *n*, the functional visual field in some sense shrank, thereby, decreasing the subjects' utilization of parafoveal information. Rayner (1986) and Inhoff, Pollatsek, Posner, and Rayner (1989) have reported similar effects.

The importance of the work on tunnel-vision type effects is quite important with respect to the present discussion. This work suggests that the notion of a relatively stable parafoveal influence is incorrect. It appears to be the case that the use of parafoveal information is dependent upon the current cognitive load. This is an especially important consideration in discussing parafoveal processes in reading where the cognitive load appears to vary considerably across fixations.

V. CONCLUSIONS

This chapter has focused on the literature addressing the influence of variables in foveal and parafoveal visual word recognition. The review has indicated that although a number of variables influence foveal processing, the safest conclusion regarding parafoveal word processing is that abstract letter code information is utilized. Such a finding is inconsistent with models of reading that place a heavy emphasis on parafoveal lexical and/or semantic preprocessing and is also inconsistent with views that minimize the role of parafoveal processing. It appears that the research in this area supports a view between these two extremes.

We have interpreted these data within an interactive threshold model of parafoveal information utilization, whereby, the influence of variables on performance seems to be limited by the degree of activation at a particular lexical-level presentation. This framework appears to be necessary to account for the consistent superadditive effects of context and parafoveal visual information. Finally, it appears that any model of parafoveal processing must eventually deal with its sensitivity to attentional demands. Very simply, the window of useful parafoveal information is not constant across different levels of demand placed on the processing system.

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FOOTNOTES

[1] It appears that the perceptual span is not symmetric around fixation. That is, Rayner, Well, Pollatsek, and Bertera (1982) found that there is relatively little distortion when information to the left of the fixated word is distorted, whereas, as noted above, distortion of information to the right of fixation dramatically influences reading performance. Moreover, this asymmetry appears to be dependent upon the particular orthography. For example, Pollatsek, Bolozky, Well, and Rayner (1981) found that for native Israeli readers that were reading Hebrew, the perceptual span was asymmetric to the left of fixation, whereas, when these same readers were reading English, their perceptual span was asymmetric to the right of fixation. The obvious difference being that English is read from left to right and Hebrew is read from right to left. The Pollatsek et al. results are particularly interesting because they suggest that the asymmetry of the window is not "hardwired" but is dependent upon reading experience and, more importantly, readers can switch from one type of asymmetry to the next dependent upon the demands of the orthography.

[2] It should be noted here, that the pattern is somewhat different when one considers the results from the gaze duration data. Here one finds that frequency has additive effects with window size. That is, when considering the total time looking at a given word, low-frequency words were looked at longer than high-frequency words, and this was independent of window size. The different pattern of results for the first fixation data and the gaze duration data indicate that subjects were much more likely to refixate a word in the one-word preview condition than in the remaining conditions. Thus, although the frequency of the target word did not influence first fixation duration on that word in the one-word window condition, it did have an impact on the probability that the word was refixated. In the one-word window condition, 33% of all refixations were on high-frequency words, whereas, 66% were on low-frequency words. This differential influence of frequency on when to leave the current fixation vs. where to send the eyes has been viewed as implicating different decisions

regarding these two components of the eye-movement system (see Pollatsek, Rayner, & Balota, 1986; Rayner & Balota, 1989).

[3] Inhoff (1987) has reported evidence that there is morphological coding in the parafovea. In this research, Inhoff compared compound words (e.g., cowboy) that were based upon two morphological subcomponents (e.g., cow and boy) and pseudocompound words (e.g., carpet) that could not be decomposed into morphological subcomponents (e.g., car and pet). Using the moving window technique, Inhoff found that there were significant parafoveal preview benefits from the word initial trigram of a compound word, but there was no significant preview effect from the word initial trigram of a pseudocompound word. However, Inhoff (1989b) has recently failed to replicate this general pattern when the compound and psuedocompound words were matched on word frequency. Inhoff did however find that preview benefits were largest for pseudocompound words that involved beginning and ending high-frequency subword units, and smallest for control words that did not contain subword units that involved lexical representations. Inhoff interpreted these results as supporting a framework in which all letters of a parafoveal word contribute to access processes, and that letters that form mutually reinforcing letter coalitions will produce additional activation. This general framework is quite consistent with the interactive threshold model described in the present chapter.

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