A Listener’s Investigation of Printed Word Processing

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The present study examines the time course of lexical access in written-word recognition by comparing words with early and late uniqueness points (UPs). Three experiments, which used a normal (simultaneous) presentation of the letters under 3 different tasks (gender classification, naming, and semantic classification) provided no evidence for sequential processing. Rather, a small advantage in favor of words with late UP was found, which may be interpreted in terms of the lower n-gram frequencies of early-UP words. Experiment 4 supported this interpretation and discussed an alternative interpretation in terms of paratope preview of the initial letters. A last experiment, which used an incremental presentation of the word letters, gave rise to a UP effect comparable in size to that obtained in an auditory study, suggesting that a temporal distribution of the signal is a sufficient condition for directional processing.

In their “A Reader's View of Listening,” Bradley and Forster (1987) proposed that despite some contrasting characteristics of the visual and auditory inputs, the lexical processes involved in written- and spoken-word recognition should not be fundamentally different. This commonality might result because reading is an artificial and relatively recent skill in humans, a skill that would have advantageously borrowed the processes previously developed for auditory recognition.

One of the most striking differences between written and spoken words is probably the way in which linguistic information is distributed over time. Whereas the reader can extract a great deal of information in parallel from the written word, the listener is confronted with a sequential and evanescent signal. This temporal distribution of the acoustic signal has led to the view that speech is processed in real time (Bagley, 1900; Cole & Jakimik, 1981; Frauenfelder & Tyler, 1987; Marslen-Wilson & Welsh, 1978).

Recent work on spoken-word recognition has provided good evidence in favor of such a process, beginning on-line during reception of the signal and allowing some words to be recognized before their end. According to the cohort model (Marslen-Wilson, 1984; Marslen-Wilson & Welsh, 1978), in which the notion of maximal efficiency was especially emphasized, the recognition point of a word should be strongly dependent on the position of its uniqueness point (UP), that is, the point at which only one candidate remains in the cohort of possible words. For nonwords, the critical point is the deviation point (DP), the point in the phoneme string at which the item is no longer compatible with any possible word candidate. As predicted by the model, Marslen-Wilson (1984) used nonwords with different positions of the DP and found that reaction time (RT) from item onset increased linearly with DP location; the slope of the relationship was close to 1 (.90). These results do not seem to have been corroborated by other studies that dealt with the effect of DP location on nonwords (Goodman & Huttonlocher, 1988; Taft & Hambly, 1986). For words, however, the evidence for an effect of UP location is quite strong: UP effects have been obtained with as many different experiments paradigms as the lexical decision task (Goodman & Huttonlocher, 1988; Taft & Hambly, 1986), the gender classification task (Radeau, Mousty, & Bertelson, 1989), the phonemic restoration illusion (Samuel, 1987), the phoneme detection task (Frauenfelder, Segui, & Dijkstra, 1990), or the shadowing task (Radeau & Morais, 1990). Note that in the studies in which quantitative estimation of the effect was provided (Goodman & Huttonlocher, 1988; Radeau & Morais, 1990; Radeau et al., 1989), the size of the effect was much smaller than the optimal value of 100% obtained by Marslen-Wilson (1984). Although this suggests that lexical monitoring continues past the UP (a notion incorporated by Marslen-Wilson, 1987, in the new cohort model), the view that spoken words are processed online is not challenged.

In single-word reading, optimal efficiency does not require sequential intake of information. Usually, all of the letters of each word are simultaneously available to the reader, and data on eye movements reveal no serial scan of the letters, at least for short words (e.g., Blanchard, McConkie, Zola, & Wolderton, 1984). The absence of sequential scanning, however, does not imply that no sequential processing takes place. One argument against entirely parallel processing comes from the studies devoted to recognition of morphologically complex words. Taft and Forster (Taft, 1979; Taft & Forster, 1976) provided evidence for some role of the first orthographic–morphological syllable, that is, the basic orthographic syllabic structure (BOSS), in the recognition of written words and in the classification of nonwords. This led to the hypoth-

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thesis that (except in prefixed words, which would be recognized
through a prefix-stripping procedure) the lexical representa-
tion of a written word might be accessed through a search
process beginning at the initial part of the word. Recently,
Cole, Beauvillain, and Segui (1989) obtained data that con-
firm this hypothesis for French printed words, even prefixed
ones; however, the search process notion, and in particular
the BOSS hypothesis, has been criticized by proponents of
connectionist models (e.g., see Seidenberg, 1987), mainly on
the grounds that the distributional properties of letter patterns
in the lexicon provide a better account of the data than any
decomposition procedure.

Another argument for some degree of sequential processing,
at least as far as words in text are concerned, comes from the
fact that in most situations the reader is able to identify and
code in an abstract form the first two or three letters of the
parasocial word at the right of fixation (Rayner & Balota,
1990). Thus, lexical access may begin on the basis of these
letters and proceed on the basis of the remaining letters after
the saccade. Moreover, processing of the initial letters may be
favored because the preferential viewing location on a word
falls about halfway between the beginning and middle of the
word (Rayner, 1979). Given that acuity decreases symmetri-
cally from the fovea to the periphery, leftward fixation gives
the initial letters some advantage. The notion that word
beginnings contribute more than other word parts to word
identification has already been proposed by Pillsbury (1897).
For instance, it is supported by the substantial parasocial
preview benefit observed on reading rate when the first two
or three letters of the word to the right of the fixated word are
available as opposed to the final letters (Inhoff, 1987, 1989;
Rayner, Well, Pollatsek, & Bertera, 1982).

We now consider the case of isolated words. We may
speculate that the systematic attentional shift to the word to
the right of fixation in the course of text reading (Morrison,
1984) has consolidated a left-to-right attentional mechanism
that operates within the word in isolated reading. But the
extent to which such an attentional mechanism might control
refreshes within words, which have been shown to depend
on word length (Rayner & McConkie, 1976) and on frequency
(Inhoff & Rayner, 1986), is unknown. In addition, if this kind
of within-word attentional mechanism existed, it would
probably be independent of between-word attentional patterns.
Inhoff, Pollatsek, Posner, and Rayner (1989) used twisted
words and provided some evidence against the existence of a
single continuous scanning process that operates both between
and within words. They manipulated the congruity of word
and letter order in a sentence by presenting either normal
words or the mirror image of the words in a left-to-right or
right-to-left order. There was no congruency effect in the
twisted condition even when parasocial information was
available. With normal words, however, the results were far
from being as clear because the size of both the congruity
effect and the preview benefit varied according to the measure
taken into account to assess reading performance.

Thus, a cohortlike model can be applied to reading by
substituting a decreasing gradient of attention from left to
right for the directionality of processing that is typical of
speech recognition. More accurate identification of the initial
letters would lead to the same predictions as if processing was
sequential.

A cohortlike model of word reading may be assumed to
predict that lexical access is easier for words with rare initial
letter clusters than for words with frequent ones because the
former clusters are more informative (i.e., they are compatible
with a smaller set of lexical candidates). This particular pre-
diction has already been examined. Lima and Inhoff (1985)
tested it in a study that was based on eye movement record-
ings. They compared high- and low-constraint words, that is,
words with rare or frequent initial n-grams (such as dwarf vs.
clown) included in short neutral sentences, by using two
moving-window conditions that differed in the presence or
absence of parasocial information. The results did not meet
the prediction, however. First fixation durations were actually
longer (not shorter) on high-constraint words than on low-
constraint ones, and there was no effect of constraint on the
parasocial preview benefit. These results led Lima and Inhoff
to conclude that the familiarity of the initial letter clusters is
more important than their informative value and that co-
hortlike models cannot account for lexical access in reading.

Nevertheless, we might argue against this conclusion that
what is critical in the cohort model is not the size of the set
of word candidates activated by word-inital information but
the reduction of this set to a single candidate. Although a rare
initial letter cluster does probably generate a smaller size set
than a frequent one, it does not necessarily reduce the set to
one unit. Lima and Inhoff (1985) did not control for the
position of the UP in their material; moreover, they used
relatively short words (4-7 letters in length, with a mean of
5.2) in which the probability of the UP being located early is
low (Luce, 1986).

In the present study, our first aim was to verify, more
directly than Lima and Inhoff (1985) did, the validity of a
cohortlike model of written-word recognition. To examine
whether the processing of written words involves a sequential
component, we compared the recognition speed of words with
early and late UPS. If written words could be recognized by
paying more attention to the initial letters than to the others
and by selecting the word candidate consistent with the initial
letters, then words with early UP would be recognized more
quickly than words with late UP. In Experiments 1-3 we used
the gender classification task, the naming task, and a semantic
classification task, respectively. In Experiment 4 we controlled
for the contribution of parasocial preview effects to our
results.

The material was the same as that used in our previous
experiments with spoken words, in which UP effects were
found with both a gender classification task (Radeau et al.,
1989) and a shadowing task (Radeau & Morais, 1990). Ex-
periments 1-3 included both mixed and blocked presentations
of the two sets of words. Experiment 4 was run with mixed
presentation only. For reasons that will be described after
this first set of experiments, a further experiment was run with a
presentation condition that more or less mimicked the se-
quential distribution of spoken words. Each word was pre-
sented incrementally, one letter at a time and at the same
overall speed as the corresponding spoken word in our pre-
vious studies (Radeau & Morais, 1990; Radeau et al., 1989).
Experiment 1

In Experiment 1 we compared recognition times for French nouns with early and late UPs by using the same material as in Radeau et al.'s (1989) and Radeau and Morais's (1990) auditory studies. We used the gender classification task already used by Radeau et al. (1989), in which the subject had to indicate by a keypress response whether each noun was feminine or masculine. Given that in that study, blocked presentation of words with early and late UP, respectively, led to a greater effect of the UP than mixed presentation, these two conditions were also used in the present experiment.

Method

Subjects. Thirty-six subjects (18 men and 18 women), students at the Université libre de Bruxelles (Brussels, Belgium), participated in the experiment. Half of the subjects were shown a blocked presentation of the items with early and late UPs, and the other half were shown a mixed presentation. All subjects were native speakers of French.

Materials. As described in Radeau et al. (1989), the words consisted of two sets of 34 trisyllabic nouns, listed in the 30,000 words of the French dictionary Le Micro Robert (Robert, 1986). The complete list is presented in the Appendix. The criterion used for deciding between early or late UP words was syllabic. In the early set, the UP always fell on the first or second syllable, whereas in the late set it fell on the third syllable. The words were selected so that their UP maintained an early or late syllabically defined position in the written form (there was one exception in the early set, however).

Visual UPs were calculated, just as the auditory UPs had been in the earlier studies, by considering all of the nouns listed in the Micro Robert (1986). On the average, they occurred on the 4.29th letter (range: 3-5) in the early set and on the 7.55th letter (range: 5-10) in the late set.

Words in the two sets were matched for mean number of letters (8.94 in the early set, range 7-12; 8.97 in the late set, range 8-11), mean number of phonemes (7.00 in the early set, range 5-9; 7.08 in the late set, range 6-9), and frequency. Mean absolute frequencies, taken from Trésor de la Langue Française (1971), were 256 (mean logarithmic value 1.74, range 0-1,920) in the early set and 291 (mean logarithmic value 1.86, range 0-1,898) in the late set.

In each set, half of the words were feminine and half were masculine. Two additional sets of 16 items, selected according to the same criteria, served as practice items.

Procedure. The experiment was controlled by an Apple IIe computer. The words were displayed in lowercase at the center of the computer screen. At the beginning of each trial, a fixation point (a cross) was presented for 300 ms. The word was presented after a 300-ms blank interval, with its first letter two character spaces to the right of the fixation point. The word disappeared as soon as the subject responded, or after 2,000 ms. Trials followed each other at a rate of 3 s/trial.

In the blocked condition, the 34 experimental items of each set of words were presented in balanced order in two separate blocks of trials. Each experimental block was preceded by a practice block of 16 trials with equivalent material. In the mixed condition, items from the two sets were presented in random order with the restriction that more than three items of one set never occurred in succession. This mixed list of experimental items was divided into two blocks of 34 trials. Practice items were presented in one block of 32 trials at the beginning of the session.

The task consisted of deciding whether the noun presented was masculine or feminine and of pressing the corresponding key as quickly as possible without making an error.

Results

Both errors and RTs that were longer than 2,500 ms or shorter than 200 ms were discarded from the analysis.

The mean RTs and error rates to early and late UP words in the two conditions appear in Table 1. The effect of UP position is opposite that observed in our previous experiments, which used the same material in the spoken form. The RTs here are about 40 ms longer for words with early than for words with late UP. Analyses of variance (ANOVAs) showed this effect to be significant for means for subjects, F(1, 34) = 23.11, MS, = 1,268.8, p < .005, and marginally so for means for items, F(2, 66) = 2.82, MS, = 18,419.0, p < .10. There was no interaction between UP position and the mixed versus blocked condition (both F1 and F2 < 1).

The blocked condition gave rise to longer RTs than the mixed condition. This effect was significant in the analysis for items, F(2, 66) = 15.98, MS, = 3,526.3, p < .005, but not for subjects, F(1, 34) = 1.71, MS, = 21,663.9, p > .10. The lengthening of RTs in the blocked condition was associated with a decrease in accuracy, F(1, 34) = 3.66, MS, = 11,021.3, p < .07.

Table 1

<table>
<thead>
<tr>
<th>Condition</th>
<th>Early UP</th>
<th>Late UP</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender classification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocked</td>
<td>813</td>
<td>769</td>
<td>-44</td>
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<tr>
<td>Error</td>
<td>2.9</td>
<td>4.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Mixed</td>
<td>764</td>
<td>727</td>
<td>-37</td>
</tr>
<tr>
<td>Error</td>
<td>6.4</td>
<td>6.1</td>
<td>-0.3</td>
</tr>
<tr>
<td>Naming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocked</td>
<td>573</td>
<td>529</td>
<td>-44</td>
</tr>
<tr>
<td>Error</td>
<td>3.9</td>
<td>3.5</td>
<td>-0.4</td>
</tr>
<tr>
<td>Mixed</td>
<td>596</td>
<td>558</td>
<td>-38</td>
</tr>
<tr>
<td>Error</td>
<td>2.2</td>
<td>1.8</td>
<td>-0.4</td>
</tr>
</tbody>
</table>

Semantic classification

<table>
<thead>
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<th>Condition</th>
<th>Early UP</th>
<th>Late UP</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocked</td>
<td>624</td>
<td>575</td>
<td>-49</td>
</tr>
<tr>
<td>Error</td>
<td>7.5</td>
<td>7.2</td>
<td>-0.3</td>
</tr>
<tr>
<td>Foil items</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocked</td>
<td>590</td>
<td>562</td>
<td>-28</td>
</tr>
<tr>
<td>Error</td>
<td>9.6</td>
<td>9.2</td>
<td>-0.4</td>
</tr>
<tr>
<td>Mixed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocked</td>
<td>620</td>
<td>584</td>
<td>-36</td>
</tr>
<tr>
<td>Error</td>
<td>12.7</td>
<td>8.6</td>
<td>-4.1</td>
</tr>
<tr>
<td>Foil items</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocked</td>
<td>581</td>
<td>563</td>
<td>-18</td>
</tr>
<tr>
<td>Error</td>
<td>10.5</td>
<td>10.7</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Note. UP denotes uniqueness point.
ated, however, with a significant decrease in error rate, \( F(1, 34) = 6.23, M_S = 21.1, p < .025 \), and \( F(1, 66) = 6.91, M_S = 31.6, p < .025 \). The error analysis showed no other significant variable or interaction.

Although cohortlike models of written-word recognition predicted that words with early UP would be recognized faster than those with late UP, we have found longer gender classification times for words with early UP than for words with late UP. This result differs from that obtained with spoken words and argues against a directional view of printed word processing. In the gender classification task, however, the decision can often be made without consulting the lexicon, on the sole basis of the ending, which as Radeau et al. (1989) have shown, provides reliable information about gender. Thus, a definite interpretation of the present result must await further evidence, which was sought in Experiments 2 and 3.

**Experiment 2**

Experiment 2 differed from Experiment 1 only in that it used the naming task. This task could be used because the stimuli in the two sets were more or less equivalent with regard to their relevance for pronunciation and print-key activation. Indeed, Sternberg, Monsell, Knoll, and Wright (1980) showed that the number of phonemes is critical. In our material, the two sets of words have the same number of phonemes on the average. Furthermore, as Radeau and Morais (1990) reported, there was no important asymmetry in initial phoneme distribution between the two sets.

**Method**

**Subjects.** Thirty-two subjects (16 men and 16 women) selected according to the same criteria as in Experiment 1 participated in the experiment, with half of them submitted to blocked presentation of the items and the other half submitted to mixed presentation.

**Materials and procedure.** Apart from the task, which consisted of pronouncing the presented word aloud, the same materials and procedure were used as in Experiment 1.

**Results**

We used the same criteria as in Experiment 1 to discard a trial from the analysis. A response was considered to be erroneous if it involved either some hesitation or a deviation of at least one phoneme in relation to the target word.

The results are presented in Table 1. They are very similar to those obtained with the gender classification task. The RTs are shorter for the late UP than for the early UP words. The effect was significant in the analyses for subjects, \( F(1, 30) = 56.55, M_S = 477.0, p < .005 \); and for items, \( F(1, 66) = 10.13, M_S = 6,170.6, p < .005 \). The UP Position \( \times \) Presentation Condition interaction was not significant (both \( F1 \) and \( F2 \) close to 0). The effect of presentation was significant in the analysis for items, \( F(1, 66) = 57.64, M_S = 412.9, p < .005 \), but not for subjects (\( F1 \) close to 1). This effect was opposite that obtained with the gender classification task because RTs were shorter in the blocked condition than in the mixed condition. The shortening of RTs was again associated with an increase in error rates, which was significant in the analysis for items, \( F(1, 66) = 6.85, M_S = 18.5, p < .025 \), but not for subjects (\( F1 < 1 \)). The analysis of errors showed no other significant variable or interaction.

The results obtained with both the gender classification and naming tasks strongly converged in arguing against a sequential view of printed word processing; however, the involvement of lexical access in naming is not completely clear. Pronunciations can in principle also be derived without lexical access by using a form of grapheme-phoneme translation (Paap, McDonald, Schwanenfeldt, & Noel, 1987). According to Coltheart's (1978) dual-route model, only irregular words would be named lexically; regular words, as well as nonwords, would be pronounced through an assembly process that used nonlexical rules. Most of the present words were regular, making orthographic lexical access unnecessary. Had the subjects used the nonlexical route in a substantial number of trials, any effect of lexical access would have been hidden. A further experiment was thus run with a task that could presumably not be accomplished without lexical access.

**Experiment 3**

In Experiment 3, we used a semantic classification task. More specifically, we chose an animal versus nonanimal classification task because the early and late UP sets of items included the same number of animal nouns. We equated the number of animals and nonanimals by introducing new animal nouns as foils. In this situation, semantic information has to be extracted to make either a positive or a negative judgment. Hence, this task presumably involves lexical access.

**Method**

**Subjects.** Thirty-two subjects (16 men and 16 women) selected according to the same criteria as in Experiment 1 and 2 were tested, half of them with blocked presentation of the two sets of items and the other half with mixed presentations.

**Materials.** The material used on experimental trials was the same as in Experiment 1 and 2 plus 56 foil items. Each set of experimental trials in the previous experiments included 3 animal nouns and 31 nonanimal ones. Therefore, the number of positive and negative responses were equated by adding two sets of 28 animal nouns as foils, one consisting of early UP items and the other consisting of late UP items. These foils were two- to four-syllable nouns matched in number of letters (8.6 in each set, range 7–11). The UP occurred on the 4.25th letter (range: 3–6) in the early set and on the 7.86th (range: 6–10) in the late one. Given the UP constraint, it was not possible to match the two sets of animal foil nouns in category exemplar typicality or in frequency. This lack of control did not really matter because the response to the foils were only considered as accessories. Mean absolute frequencies, according to Trésor de la Langue Française (1971), were 65.11 (mean logarithmic value, 1.47; range: 0–470) for the words of the early set and 129.60 (mean logarithmic value, 1.65; range: 0–914) for those of the late set.

Animal nouns (8 with early UPs and 8 with late UPs) were substituted for 16 nonanimal nouns in the practice list. Thus there was the same number of animal and nonanimal items and within each of these sets the same number of early and late UP items.

**Procedure.** The only differences among this experiment and the previous ones concerned the task (the subject was required to indicate
by a keypress response whether the presented item was or was not the name of an animal) and the number of trials per session (124 instead of 68). Each blocked and mixed presentation condition consisted of two blocks of trials each including 31 nonanimal experimental nouns, 3 animal experimental nouns, and 28 animal foil nouns.

Results

The data of each presentation condition are presented in Table 1 separately for the experimental and foil nouns. Because experimental trials included only three trials (of 34 in each set) that led to a positive response, a separate analysis of positive and negative responses was pointless. Moreover, elimination of some items would alter the matching of the two sets of words in terms of mean frequency and mean number of letters. We submitted the data to ANOVAs with trial type (experimental vs. foil), UP position, and presentation condition as variables. The results are similar to those of the other experiments: Words with early UPS were classified more slowly than those with late UPS. This effect was significant in the analysis for subjects, $F(1, 30) = 14.37, M^2 = 2.3683, p < .005$, and in the analysis for items, $F(2, 120) = 4.23, M^2 = 12.5132, p < .05$. Classification times were faster for foil nouns than for experimental ones. This effect was significant in the analysis for subjects, $F(1, 30) = 14.39, M^2 = 1.6198, p < .005$ and marginally so in the analysis for items, $F(2, 120) = 3.80, M^2 = 12.5132, p < .10$. The difference may occur because foil items consisted exclusively of animal nouns and thus led to positive responses, whereas experimental items involved mostly nonanimal nouns (31 of 34), which required negative responses.

The interaction between UP position and trial type was significant for subjects, $F(1, 30) = 5.60, M^2 = 59.2, p < .025$, and did not reach significance for items ($F/2$ close to 1). For experimental nouns, the effect of UP position was significant for subjects, $F(1, 30) = 25.97, M^2 = 1.1129, p < .005$, and for items, $F(2, 120) = 5.47, M^2 = 12.2304, p < .05$. For foil nouns, it was still significant for subjects, $F(1, 30) = 4.55, M^2 = 1.8146, p < .05$, but not for items ($F/2$ close to 0). Interpretation of UP effects in foil trials, however, is subject to caution because foil nouns were not matched in terms of frequency. Actually, early UP foils were rarer than late UP ones, and this might account for the lengthening of RTs in the early set. In no analysis was there any effect of the blocked-mixed presentation condition (both $F1$ and $F2$ close to 0).

Although error rates followed the same pattern as RTs, the ANOVAs run on error rates did not reveal any significant effect or interaction.

Joint Analysis of Experiments 1–3

Two ANOVAs (one for subject and one for item) carried out on the data of the three experiments (experimental items only) showed no difference in the size of the UP effect across tasks, as reflected by the lack of interaction between task and UP position (both $F1$ and $F2$ close to zero). However, the three tasks gave rise to RTs that were significantly different in the analyses for subjects, $F(2, 97) = 59.20, M^2 = 13.7218, p < .005$, and items, $F(2, 132) = 146.8, M^2 = 11.1343, p < .005$. The RTs were significantly shorter in naming than in both semantic classification—$F(1, 62) = 4.80, M^2 = 8.9904, p < .05$, and $F(2, 1, 66) = 14.28, M^2 = 9.3983, p < .005$—and gender classification—$F(1, 66) = 85.99, M^2 = 16.3386, p < .005$, and $F(2, 1, 66) = 367.92, M^2 = 3.9831, p < .005$. They were also shorter in semantic classification than in gender classification, $F(1, 66) = 60.7, M^2 = 15.5497, p < .005$, and $F(2, 1, 66) = 114.0, M^2 = 15.9943, p < .005$. Error rates did not follow the same pattern as RTs. Naming responses, however, were not only faster but also more accurate than gender classification responses—$F(1, 66) = 7.86, M^2 = 2.2, p < .01$, and $F(2, 1, 66) = 4.81, M^2 = 59.2, p < .05$—and semantic classification responses—$F(1, 62) = 30.77, M^2 = 4.6, p < .005$, and $F(2, 1, 66) = 12.21, M^2 = 198.9, p < .005$. Semantic classification, though faster than gender classification, was significantly less accurate, $F(1, 66) = 13.73, M^2 = 4.7, p < .005$, and $F(2, 1, 66) = 4.54, M^2 = 23.11, p < .05$.

The observation of shorter RTs for late UP words than for early UP words agrees with Lima and Inhoff's (1985) finding that high-constraint words receive longer fixations than low-constraint words. Lima and Inhoff interpreted this as resulting from the lower frequency of the beginning letter clusters of the high-constraint words in relation to those of the low-constraint words. It might be assumed that the same factor was responsible for the lengthening of RTs for the words with early UP in the present experiments, because by definition these words share their first letter clusters with few other words.

To examine this possibility, we compared the two sets of words with regard to different measures of consistent bigram frequency by using Content and Radeau's (1988) textual frequencies for French language. These frequencies were obtained by summing the number of words in which the bigram appeared in a given position (initial, median, or final) multiplied by the frequency of the corresponding words. We compared the two sets of words with regard to the logarithmic frequency of the initial bigram and the averaged logarithmic frequency of the successive bigrams included in the word. As could be expected from the definition of the UP, it appears that words with early UPS have rarer bigram frequencies than those with late UPS. This holds for the initial bigram frequencies (2.33 and 2.65, respectively) and for the word bigram frequencies (2.59 and 2.78, respectively).

We calculated the correlations between these measures of bigram frequency and the RTs for item for each experiment, taking into account averaged RTs for the mixed and blocked presentation conditions. In the three experiments, we found significant negative correlations between RTs and initial bigram frequency: Experiment 1, $r = -.29, p < .01$; Experiment 2, $r = -.22, p < .05$; Experiment 3, $r = -.30, p < .01$. In Experiments 1 and 2, the negative correlations between RTs and word bigram frequencies were also significant: Experiment 1, $r = -.33, p < .01$; Experiment 2, $r = -.29, p < .01$.

We ran stepwise multiple regression analyses to assess the contribution of these measures of bigram frequency to the RTs. Our results were not significant between initial bigram and word bigram frequency, $r = .48, p < .01$. The results of the three analyses appear in Table 2. The RTs were predicted best by word bigram frequency in Experiments 1 and 2 and by initial bigram frequency in Experiment 3.
Table 2
Partial Slopes and Partial Correlations Among Reaction Times (Average of Mixed and Blocked Conditions), Word Bigram Frequency, and Initial Bigram Frequency in Experiments 1–3

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Word bigram</th>
<th>Initial bigram</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-177.99</td>
<td></td>
</tr>
<tr>
<td>Partial slope</td>
<td>-33</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>-63.59</td>
<td></td>
</tr>
<tr>
<td>Partial slope</td>
<td>-29</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>-30.28</td>
</tr>
<tr>
<td>Partial slope</td>
<td></td>
<td>-26</td>
</tr>
</tbody>
</table>

Note. A dash indicates that the variable did not enter the equations.

The effect of bigram frequency observed in the present experiments is consistent with Lima and Inhoff's (1985) finding that the duration of the first fixation on a written word depends more on the familiarity of its letter clusters than on their informativeness.

It might be argued that the evidence for the role of orthographic factors in our results is an artifact of the presentation procedure. In order to favor a left-to-right reading of the words, the fixation point was presented two characters to the left of the first word letter. Initial eye fixation to the left of the word would thus have made the first letters fall in the parafovea. As noted in the introduction, there is good evidence that in normal reading, parafoveal preview provides orthographic information and affects fixation duration (Morris, Rayner, & Pollatsek, 1990; Rayner, 1984; Rayner & Balota, 1990). Consequently, parafoveal preview of the first letters of the words might have been responsible for the effect of bigram frequency observed in the three experiments. Moreover, if the bigram frequency effect gives the set of items with late UP a strong advantage, it might even have concealed the UP effect predicted by a cohort model. This possibility was tested in the following experiment.

Experiment 4

In this experiment, the words were centered on the fixation point. The same gender classification task was used as in Experiment 1. Items were presented in a mixed condition only.

Method

Subjects. Sixteen subjects (9 women and 7 men) participated in the experiment.

Materials and procedure. The position of the cross that served as fixation point coincided with the middle of the word. Everything else followed the same procedure as for the mixed condition of Experiment 1.

Results

The mean RTs and error rates are presented in Table 3. The results are similar to those obtained for the mixed condition of Experiment 1 with the same gender classification task. The effect of the UP is again negative. The lengthening of RTs for early UP words was significant in the analysis for subjects, $F(1, 15) = 9.81, M_S = 935.5, p < .01$, but not items, $F(2, 66) = 1.90, M_S = 9,871.3, p = .17$. There was no significant difference in error rates between the two sets of words (both $F1$ and $F2$ close to 0).

We again considered the contribution of both initial bigram and word bigram frequency to RTs for items. The correlation between RT's and word bigram frequency was significant, $r = -30, p < .01$, and the slope of the regression function was $-109.21$. For initial bigram frequency, the correlation ($r = -15$) fell short of significance.

Obtaining a negative UP effect with a fixation point that occurred in a position corresponding to the middle of the word argues against an interpretation of this effect in terms of parafoveal extraction of letter-code information, which resulted from the presentation procedure used in Experiments 1–3.

Discussion: Experiments 1–4

Although cohortlike models of written-word recognition predicted that words with early UPS would be recognized faster than those with late UPS, we have found longer recognition times for words with early UPS than for those with late UPS. Similar results were obtained with three different tasks. This is worth noting because although it is possible that one of the tasks presents its own specific shortcomings, the most parsimonious way to account for the converging results is to assume that lexical access in word reading does not make use of the UP. This conclusion is reinforced by the fact that in the first three experiments, the location of the fixation point may have induced a bias toward directional processing. Moreover, the possibility that this presentation procedure had prevented the effect of UP location from manifesting itself because of contamination through parafoveal preview is ruled out by the results of Experiment 4. In that experiment, with initial fixation in the middle of the word, the negative effect of UP location was as big as in Experiments 1–3, with fixation to the left of the word. Of course, this result does not rule out the existence of parafoveal preview effects. In our experiments, the fixation point may have acted more as a warning signal than as an anchoring position for the eyes. Indeed, eye position was not controlled, and the subjects were not explic-
ity required to fixate the cross before starting to read the items. The present data suggest that whatever the importance of written-word beginnings, the reader does not select whenever possible the lexical entry uniquely specified by the initial letter string.

The results of the regression analyses between RTs for items and bigram frequency are consistent with the view that the disadvantage for early UP words was due to differences in orthographic structure between the two sets of words. Other interpretations, however, might be proposed. One of them would attribute the results to differences in neighborhood size between early and late UP words. Through the use of both the lexical decision task and the naming task, Andrews (1989) reported evidence for facilitatory effects of large neighborhoods for low-frequency words. Although this result seems to conflict with other data (e.g., see Coltheart, Davelaar, Jonasson, & Besner, 1977; Grainger, O’Regan, Jacobs, & Segui, 1989), the possibility that the advantage for late UP words was a side effect of neighborhood size deserves consideration.

We calculated the number of neighbors of each word in the present material with Brulex, our lexical database for French (Content, Mousry, & Radeau, 1990), by using the N measure described by Coltheart et al. (1977). The mean number of words that can be generated by changing only one letter in the target word is 0.12 (range: 0–2) in the early set and 0.15 (range: 0–1) in the late set. These extremely low values of neighborhood size make unlikely the possibility that late UP words are recognized faster because they have larger neighborhoods.

Another interpretation of our pattern of results is that the effect of bigram frequency is actually an effect of pronunciation regularity, because low-frequency bigrams are correlated with irregular pronunciation. Only three of the early UP words, however, contained a bigram with obvious irregular pronunciation (the underlined bigram in the following words: caoutchouc, stagnation, orchidée). For each experiment, mean RTs for items for early UP words were recalculated after elimination of the three irregular items. There was little difference between these new RTs and those including the irregular words. The RTs for the 31 regular early UP items for the blocked and mixed conditions, respectively, are now 811 ms and 769 ms (instead of 813 ms and 764 ms) in Experiment 1, 571 ms and 592 ms (instead of 573 ms and 596 ms) in Experiment 2, and 635 ms and 635 ms (instead of 624 ms and 620 ms) in Experiment 3. In Experiment 4, with mixed presentation, the new mean RT is 725 ms instead of 729 ms. These small and unsystematic differences between RTs with or without the three irregular items suggest that the disadvantage for early UP words did not result from irregular orthographic–phonologic correspondence. Of course, this does not rule out a further account in terms of consistency or rule strength effects (Van Orden, Pennington, & Stone, 1990). As Glushko (1979) pointed out, there are words that are regular but inconsistent in that they contain letter patterns that have an irregular pronunciation in other words. Such inconsistencies have been shown to lengthen naming latencies, at least in the case of low-frequency words (Rossen, 1985). No normative data exist with regard to pronunciation consistency in French, however, so it was impossible to estimate the contribution of consistency effects of orthographic–phonologic correspondence to our data.

We found no interaction between the effect of UP position and the presentation (blocked–mixed) condition. If subjects do not process the words sequentially, there is no reason to expect the negative UP effect to be influenced by the expectancy of items of a particular UP type. Thus, the lack of interaction between UP and presentation condition suggests that information from the letter string is extracted in parallel. Note that different results were obtained for the recognition of spoken words: Radeau et al. (1989) have reported a greater UP effect in the blocked condition than in the mixed condition. This suggests that when it occurs, sequential processing may be at least to some extent under the subject’s control. This discrepancy between spoken- and written-word recognition results reinforces the notion that the written-word processing used in the present tasks is not sequential.

This difference between the processes involved in listening and reading raises the question of the conditions that underlie sequential versus nonsequential processing in word recognition. Indeed, spoken and printed words differ with regard to the way in which information is distributed in both modalities. A further important difference is that unlike reading, which is a cultural and comparatively recent skill, speech processing is a natural and much older system that through evolution might have become optimally adapted to the temporal nature of its input (Bradley & Forster, 1987). Thus one may wonder if the temporal distribution of input information is a sufficient condition for sequential processing to occur. This question rarely seems to have been considered, except for some work carried out in our laboratory on the recognition of isolated braille words by blind braille readers, in which clear effects of UP location consistent with the notion of on-line processing have been obtained (see Bertelson, Mousry, & Radeau, 1992). In the following experiment, we examine the question for the case of written presentation.

Experiment 5

It is possible to present printed words sequentially, for instance, letter by letter. Bradley and Forster (1987) described an incremental presentation situation that M. Blosfelds used in their laboratory in which the letters of a word are displayed progressively on the screen, starting from the left; each new letter appears to the right of the previous one. For example, presentation of a word like spaghettì involves the successive displays s, sp, spa, spag, spagî, spaghè, spaghettî, and spaghettì. Bradley and Forster (1987) mentioned that subjects find it very difficult to deal with a strictly sequential situation in which each letter is erased at the time the following one is displayed, but subjects adapt easily to the incremental situation. A somewhat related way of displaying text is the one used in advertisements in which words are moved across a fixed window. In this experiment, the words used in the first experiments were presented in the incremental mode at a speed designed to match the duration of the spoken delivery.

Mewhort used sequential presentation of letters in a number of experiments with both nonwords (Mewhort, 1974) and words (Mewhort & Beal, 1977). For example, Mewhort and
Beal (1977) presented each letter of a set of eight-letter words during 5 ms with an interletter interval ranging from 0 ms to 250 ms. The subjects had to name the word aloud when possible or otherwise to spell as many letters as they could. In a normal condition (with forward orientation and left-to-right presentation of the letters), the percentage of correct word identification was close to 100 at the zero interletter interval, but it declined sharply at longer intervals, for which letter spelling increased. The zero interval provides a presentation pattern that looks very much like the whole-word one, because with 5 ms of presentation time by letter, it took only 40 ms for an eight-letter word to be displayed completely. The decrease in the number of word responses observed at slower rates is consistent with Blosfeld's comment, reported by Bradley and Forster (1987), about the difficulty of dealing with sequential presentations. Indeed, it may be assumed that Blosfeld, in her attempt to compare visual- and spoken-word recognition, used presentation times longer than 5 ms per letter or (and) interletter intervals longer than 0 ms.

The aim of Experiment 5 was to determine whether an incremental, letter-by-letter presentation of a printed word might give rise to sequential processing. If the sequential presentation of the information is a sufficient condition for directional processing to occur, then we expect to observe a UP effect. If, however, directional processing requires a mechanism that has evolved to deal specifically with temporally distributed material (as is the case for speech) and that is unusable for other materials, then we would not expect to observe a UP effect.

The gender classification task was used. This task was preferred to both naming and semantic classification because Radeau et al. (1989) used it for the recognition of spoken words, and thus a direct comparison between the two modalities could be made.

Method

Subjects. Sixteen students (5 men and 11 women) from the Université libre du Bruxelles, selected according to the same criteria as in the other experiments, served as subjects.

Materials and Procedure. The materials were the same as in the other experiments. Mean UP position from word onset was 453 ms in the early set and 794 ms in the late set. The difference between the mean temporal positions of the UPs in the two sets was thus 341 ms. Mean word length was 940 ms in the early set and 955 ms in the late set.

Subjects were required to classify each noun as male or female, as in Experiment 1. The items were presented in a mixed sequence only. The experiment was controlled by two Apple IIGS computers, with one controlling stimulus display and the other controlling the subject's response. Trial presentation followed the same procedures as in Experiments 1-3. At the beginning of each trial, however, dotted lines representing the total length of the word were presented one character space under the word. This was expected to prevent the subject from responding to words other than the target ones in cases in which a word was embedded in the target, for instance, savon in savonnette.

The words were presented one letter at a time. Each letter was added to the previous one after a time that corresponded to the real duration of the auditory word divided by its number of letters, after which the word disappeared. The duration of the visual presentation was thus equivalent to the auditory presentation with a precision of ±10 ms.

Results and Discussion

The mean RTs and error rates are presented in Table 4. The main difference between these results and those obtained in the first experiments, with normal simultaneous presentation of word letters, is that here there is a positive UP effect. The RT is 109 ms shorter for words with early UPs than with late UPs. We conducted ANOVAs that showed this difference to be significant for subjects, F(1, 15) = 62.07, MS = 1,526.1, p < .005, and items, F(1, 66) = 8.37, MS = 26,364.5, p < .01. Although there was a trend for late UP words to be associated with more errors than early UP words, the analysis of error rates revealed no significant difference between the two sets of words (both F1 and F2 close to 0).

We also analyzed mean RTs for items as a function of the temporal distance of the UP from word onset. The slope of the regression function for mean RTs and UP position was 42 (r = .53, p < .001).

The results obtained with letter-by-letter presentation of printed words resemble those observed with spoken words (Radeau et al., 1989) and the same gender classification task.

With a mixed sequence of presentation of the items, the auditory UP effects reached 133 ms (Experiment 1, Condition 1) and 110 ms (Experiment 2, Condition 1), and the slopes of the regression functions for mean RTs for items and UP position were .40 and .37, respectively. These effects were thus quite comparable in size to those obtained in the present experiment. Like the auditory UP effect, which represented about one third of the difference between UP positions from word onset for the two sets of words (359 ms), the present UP effect also represented one third of the corresponding difference between the visual UPs (341 ms). This suggests that other variables besides the location of UP contribute to the RT, such as the length of the word. The reason for the effect of word length might be the occurrence of some processing beyond the UP, the extent of which would increase with the amount of data following the UP.

In the present study, RT correlated significantly with word length (r = .70, p < .001). Note that UP position also correlated with word length (r = .38, p < .001) and that no correlation was found between RT and either initial or word bigram frequency. We ran a multiple regression analysis to assess the relative contribution of UP position and word length to the RT. The independent variable that mostly predicted RT was word length (partial slope, .68; partial

<table>
<thead>
<tr>
<th>Measure</th>
<th>Early UP</th>
<th>Late UP</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>UP position</td>
<td>4.53</td>
<td>7.94</td>
<td>3.41</td>
</tr>
<tr>
<td>RT</td>
<td>1.374</td>
<td>1.485</td>
<td>0.109</td>
</tr>
<tr>
<td>Error</td>
<td>7.0</td>
<td>8.3</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Note. UP denotes uniqueness point.
correlation, .54). The UP position also entered significantly in the equation (partial slope, .25; partial correlation, .29). These results are in agreement with the report by Radeau and Morais (1990) of a contribution not only of the UP but also of word length to the shadowing latencies of spoken words.

Conclusions

The data of Experiments 1–4, through normal (simultaneous) presentation of word letters in three different tasks and two presentation conditions of the fixation point, have provided no evidence of an advantage for early UP words over late UP ones. These results agree with those obtained by Lima and Inhoff (1985) with regard to durations of first eye fixation on high- and low-constraint words. It thus seems clear that printed-word processing does not occur sequentially and that recognition does not result from the progressive attribution of a cohort of lexical candidates as successive letters are analyzed. This conclusion might seem consistent with the view that there is no letter-by-letter scanning of the letters within a word (Blanchard et al., 1984). The evidence for parallel processing, however, has been obtained for short words that receive only one fixation. In the present study, the mean number of letters per word was 9. As Carr and Pollatsek (1985) discussed, words longer than 6 or 7 letters receive two or more fixations from which the information has to be combined and integrated. Although such words “exceed the limits of parallel information extraction” (Carr & Pollatsek, 1985, p. 70), our data have not provided the least piece of evidence in favor of the view that printed words, even long ones, would be processed in a cohort-like fashion.

Rather than being processed more rapidly, early UP words are processed more slowly than late UP ones. This negative UP effect is significant in the four experiments that used simultaneous presentation of the letters, whether the fixation point was to the left or in the middle of the word. Again, this is consistent with Lima and Inhoff’s (1985) finding that high-constraint words receive longer eye fixation than low-constraint ones do. We proposed, as Lima and Inhoff did, that the negative effect of the UP is a side effect of n-gram frequency. As a matter of fact, graphotactic constraints have been shown to be negatively correlated with written-word recognition time (Massaro, Taylor, Venzky, Jastrzembski, & Lucas, 1980; Scheerer, 1987; Venzky & Massaro, 1987). This interpretation is supported by the observation of negative correlations between RTs and either word bigram frequency or initial bigram frequency in all the first four experiments of the present study. As shown in the discussion of those experiments, other interpretations of this effect in terms of smaller neighborhood size (Andrews, 1989) or of less regular pronunciation for early UP words can be ruled out. Nevertheless, the hypothesis that consistency of orthographic–phonological correspondence has contributed to the effect (Van Orden et al., 1990) remains open.

With incremental presentation of the word constituents, a radically different pattern of results was found. An effect of UP going in the same direction as that observed with spoken words was obtained: early UP words were responded to more rapidly than late UP words. The effect was as large as in the spoken-word recognition experiment of Radeau et al. (1989), in which the same material and the same task were used. The results of the incremental presentation experiment suggest that the condition for word processing to be sequential is that information be temporally distributed. It thus seems that sequential processing of a given material does not critically depend on extensive receiving of this material over time. It should not be forgotten, however, that our incremental presentation experiment used letters as presentation units. Different results could be obtained if the words were temporally fragmented in other ways. The strength of the links between adjacent letters is variable and can be relevant for written-word recognition. By using a letter-by-letter presentation, we probably minimized differences in the strength of those links. Thus, we plan to carry out a systematic exploration of the relations between the UP effect and the incremental presentation conditions. In particular, we will manipulate the number of presentation steps as well as the relation between these steps and different types of orthographic and phonological units.

References


Appendix

List of Words With Early and Late UP Used in the Study

In each item, the underlined character indicates the position of the UP.

**Early UP**: aptitude, piseplut, mademoiselle, buanderie, abandon, nicotine, ritournelle, cagouche, ricechet, garnement, stagnation, farandole, monument, crustacé, atelier, taupe, ustensile, cassoulet, orchidée, majuscule, camembert, sarabande, rhapsodie, esplanade, adjectif, chimpanzé, véragda, scarlatine, véhicule, spaghetti, pamplemousse, trahison, dromadaire, and irruption.

**Late UP**: machineire, tourterelle, écureuil, colonnade, agression, porcelet, balancier, rotisseur, anarchie, inventrice, chemisier, tragédien, mécanisme, aquarelle, directoire, confession, chapelier, créature, cordonnet, assistance, voyageuse, dynamisme, savonnette, imprimérie, patinoire, allumage, écritau, trésorier, chevalerie, escalope, ramassis, tentative, avantage, and balayage.

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