Detection of Fs in a single statement: The role of phonetic recoding

J. DON READ

University of Lethbridge, Lethbridge, Alberta, Canada

Most college-student readers have difficulty in detecting the letter F in instances of the word OF embedded in a single statement. Throughout a series of five experiments designed to clarify the basis of these detection failures, their unique and robust nature was demonstrated. The detection failures persisted in spite of repeated attempts to detect the letters by subjects who, in separate conditions and experiments, first memorized or copied the statement, or who, for purposes of comparison, also detected the O in OF, the N in ON, or the F in IF, or who read the statement in a number of physical formats, which included lower and upper letter cases, scrambled syntax, unsegmented letter strings, and vertical (list) presentation. Although many of these manipulations significantly improved performance, none produced perfect performance or performance comparable to the detection of F in IF. Several hypotheses, including those of redundancy, unitization, and phonetic recoding, were tested as explanations of the detection failures: The hypothesis that received the strongest support was that of phonetic recoding. This hypothesis focuses upon the atypical pronunciation of F as /v/ (as in the word OF), rather than as the more typical /f/. In short, this reading illusion was concluded to be, in large part, a result of the subjects' scanning their acoustic rather than their visual images of the printed word.

Read the following sentence and count the number of instances of the letter F within it: FINISHED FILES ARE THE RESULT OF YEARS OF SCIENTIFIC STUDY COMBINED WITH THE EXPERIENCE OF YEARS.¹ Although the correct number is six, the majority (85%-90%) of adult readers first attempting the statement detect only three Fs. Indeed, many discover that they must read it numerous times to detect more than three Fs, and, in some cases, the remaining Fs are never detected. I have witnessed colleagues and students becoming incensed when assured that six Fs can be found. When their detection failures continue, their next reaction is to assume that the Fs must be represented in some other spatial form: for example, the spaces between letters. The missing or undetected Fs are always those in the three instances of the common function word OF.

The five experiments reported here were concerned exclusively with the failure to detect the F in the word OF. The data were collected during in-class demonstrations of the difficulty of this seemingly simple task. Interest in these failures stems from several sources. First, such detection failures occur reliably and in spite of readers' high levels of motivation to perform well. In this regard, the compelling nature of readers' detec-

tion failures are similar to visual illusions for which, try as they might, viewers continue to perceive a distorted stimulus. The study of visual illusions frequently has provided valuable information about normal perceptual processes in vision (see Coren & Gergus, 1978, for a discussion of these insights); similarly, it was thought that a study of this reading illusion might shed light on reading processes. Second, the research fell easily into a series of recent studies on the detection of letters and proofreading errors in the words *the* and *and* and in the word ending *-ing* by Healy and Drewnowski (e.g., Drewnowski, 1978; Drewnowski & Healy, 1977, 1980, 1982; Healy, 1976, 1980, 1981); in these studies, a number of hypotheses about the forms and variety of reading units have been developed. Several of these hypotheses were tested as explanations of the detection failures of the F in OF.

The hypotheses that may be suggested to account for the detection failures of F fall into two general categories. Included in the first category are hypotheses related to the special status of the word OF as a short, extremely high-frequency function word or as an integrated unit of reading. The second category includes those hypotheses related to the pronunciation of the letter F in OF as /v/, as opposed to its more common pronunciation, /f/. Within the first category, the "redundancy" hypotheses (Corcoran, 1966; Healy, 1976, 1980) would suggest that the reader fails to detect the F because the word OF is highly predictable in a meaningful sentence on both semantic and syntactic grounds and that, as a consequence, the reader directs few fixations to it (e.g., Rayner, 1978). Or, in spite of being

Thanks are due Irene Wnek and Susan Cross-Calvert for assistance in data analysis, and to Richard Hammersley, John Vokey, Keith Humphrey, and Melvin Komoda for their critical readings of the manuscript. Melvin Komoda suggested Experiment 5. Reprint requests should be addressed to: J. Don Read, Department of Psychology, University of Lethbridge, Lethbridge, Alberta T1K 3M4, Canada.

fixated, the word is ignored because the reader has learned, through years of experience, to ignore noninformative function words (see Schindler, 1978). The "unitization" hypothesis, on the other hand, argues that the reading process incorporates units larger than the letters themselves and that identification of the constituent letters by skilled readers in a common word like OF is difficult and requires special attention and instruction (Drewnowski & Healy, 1982; Healy, 1980). Because OF is the second most frequent word in English—according to Kučera and Francis (1967), it occurs some 36,000 times per million words—both the redundancy and the unitization hypotheses are well prepared to handle the detection failures of F. Similarly, both of these hypotheses would predict that if readers are forced to go beyond normal reading activities (that is, to move away from phrase, word, and syllable processing to letter-by-letter processing), the letters will be detected.

The second category, the phonetic-recoding hypotheses, on the other hand, would place the emphasis upon the response rather than on the perceptual units in reading and would assume that the errors are made because the F in OF is pronounced /v/ rather than /f/. Since OF is the only word in English for which this atypical pronunciation occurs (Venezky, 1970), the reader is ill prepared to interpret the sound of /v/ as an instance of the letter F. In short, the process of decoding from letters to sounds and the relatively invariant grapheme-to-phoneme correspondence of F produces the detection failure. Locke (1978), for example, demonstrated that individual target letters are more frequently not detected when their phonetic forms are atypical than when they are typical. A weaker version of the general phonetic-recoding hypothesis would suggest that the detection failures of F are restricted to the particular statement used in these experiments, since the presence of the more typical /f/ sound in the words FINISHED, FILES, and SCIENTIFIC earlier in the sentence has given the reader a set to search only for the /f/ sound.

Each of the above hypotheses is tested in the following experiments. To anticipate, the conclusion of these studies is that the phonetic-recoding hypothesis is most consistent with the data: Since the pronunciation of F in OF depends upon the letters O and F being read as the single word and syllable unit OF, those variables that affect the probability of such a pronunciation affect the detection of F in OF.

EXPERIMENT 1

Because my initial interest in this problem developed from being witness to the frustrated, unrecorded, attempts of others to correctly locate the six Fs in the statement mentioned above, the first experiment was designed to document the magnitude and generality of

the detection failures. Informal use of the statement in introductory psychology classes indicated that only the unusual student could detect all six Fs after a single reading. Schindler and Jacobs (Note 1) similarly noted the prevalence of the detection failures of F in this statement. The questions asked in the first experiment focused on the redundancy and unitization hypotheses: Would performance change with increased attentiveness to the statement? If subjects are forced to read the statement more often, more slowly, and more carefully, eye fixations upon and increased processing of the OF words should decrease the detection failures. To answer these questions, three separate counts of the Fs were made by subjects in four different experimental conditions.

Method

Subjects. All of the data to be reported in this paper were collected with groups of introductory psychology students at the University of Lethbridge. The total numbers of subjects who served in Experiments 1-5 were, respectively, 356, 275, 145, 369, and 33. The data were collected in classroom settings and in groups that ranged in size from 33 to 96 students. In several instances, different experimental groups were obtained through the simultaneous presentation of different written instructions to subgroups of students within a single class.

Design, Materials, and Procedure. The statement was typed in capitals and reproduced as a 35-mm slide for presentation to the subjects. Each subject received a four-page booklet. The first page provided spaces for his or her name, age, and sex. On each of the following three pages, only the following statement was printed: "The number of Fs in the statement is ____." The subjects turned to each page only when instructed and were asked to not go back to previous pages. The instructions on each of three test trials requested the subjects to read silently the statement and then to count the number of Fs.

Four experimental groups were used. The first group ($n = 136$) represented the baseline, or control, assessment of the difficulty of the F-detection task following standard instructions. The remaining three groups received different instructions prior to the second test trial only. One of these, the recall group ($n = 96$), was instructed to memorize the statement verbatim. These subjects studied the statement for a 2-min period, the projector was then turned off, and they immediately wrote the statement from memory on the second page of their test booklets. They then counted the number of Fs in their handwritten statements. The remaining two groups received instructions, prior to the second test, to copy exactly the statement onto the second page of their response booklets. For 71 of the subjects (the copy-P group), the copying task was to be completed with the preferred (P) hand; for the other 53 subjects (the copy-NP group), the statement was copied with the nonpreferred (NP) hand. Following the copying task, the subjects counted the number of Fs in their written statements. The intent of the recall and copying instructions was to increase the degree of the subjects' attentiveness to the statement. If the Fs are not normally detected because of the special role of the word OF, then more detections should occur in these groups. I also anticipated that the added difficulty of copying with one's nonpreferred hand should produce the greatest number of detections because of the increased letter-by-letter attention given during both writing and reading of their statements. Finally, on the third test trial, all subjects again counted the number of Fs in the statement in a manner identical to that on the first trial. Throughout the testing procedure, the subjects were not informed of the correct answer or of the accuracy of their answers.

Results and Discussion

Two dependent variables were assessed: the percentage of subjects in each group on each trial who correctly detected all six Fs and the percentage of Fs detected by each subject in the written and projected versions of the statement. In the recall, the copy-P, and the copy-NP conditions, the values of the dependent variables on the second trial were based upon the actual numbers in their written versions. In all analyses and in all experiments reported here, these two dependent measures produced essentially identical outcomes. To demonstrate the generality of the F-detection failures across subjects, both measures are presented in Figure 1.

The left panel of Figure 1 presents the percentages of subjects in each condition who correctly recorded a count of the Fs that matched the number available on each of three test trials; the right panel presents the percentage of Fs detected. The subjects never recorded more Fs than were available. What is immediately striking about these data is the poor performance in all experimental conditions: Even with three attempts to detect all the Fs in this single statement, between 35% and 75% of the subjects were unable to do so. In the control condition, this figure remained above 65%. At least two of the Fs were usually missed by these subjects. Furthermore, since the average number of attempts by the subjects to count the letters was probably greater than three because of the uncontrolled nature of group testing, the difficulty of detecting the Fs is astonishing indeed. As expected, the performance of the recall and copy groups was significantly better on the second trial than that of the control group, and this advantage was maintained on the third trial. Nevertheless, as many as 35% of these subjects continued to miss at least one of the Fs after these intensive experiences. The percentage of the six Fs not detected on the first trial was 40%. Since all of these errors occurred on the word OF (as demonstrated in Ex-

periment 3), the conditional error rate (errors on OF divided by total errors) is 100% and the absolute error rate on OF is close to 80%. For purposes of comparison, in studies using prose passages, Corcoran (1966) found 32% errors on the detection of *e* in instances of *the* and Schindler (1978) reported 13.7% detection errors on letters in a variety of function words. Because errors on OF are more common than errors on *the* but *the* is twice as frequent as OF in English, immediate doubt is cast upon the unitization hypothesis as being the sole explanation of the F-detection failures.

Analysis of variance of these data revealed significant main effects of experimental groups [$F(3,352) \geq 9.30$], test trials [$F(2,704) \geq 178.96$], and their interaction [$F(6,704) \geq 10.38$]. Unless otherwise indicated, effects reported as significant in these experiments exceeded the .001 probability level. In short, all groups improved their performance over trials, but at significantly different rates. Two points about the recall and copy groups should be made. First, since the performance of the recall group represents a situation in which the Fs are recalled by subjects but are not recognized, it seems likely that the word OF is normally treated as a single unit when produced in written form. Second, since the activity of copying in the P and NP conditions produced immediately superior performance to that in the control condition but failed to further improve performance on Trial 3, the effects of these instructions appear to be specific to the materials scrutinized on a particular test trial.

EXPERIMENT 2

The results of Experiment 1 demonstrated the considerable difficulty of detecting Fs in the statement and seemed to indicate that this difficulty is not due to any failure of the subjects to attend to the task. Nevertheless, it is still possible that the subjects neither fixated

Figure 1. Percentage of subjects obtaining a perfect score (left panel) and percentage of letters detected (right panel) on each of three test trials in each condition of Experiment 1.

upon nor specifically attended to the word OF in Experiment 1. Although Just and Carpenter (1980) were able to show that function words are indeed fixated in normal reading, the durations of these fixations are relatively brief. Experiment 2 asked whether subjects failed to detect the F because they failed to attend sufficiently to the word OF or because they were unable to process the word OF at the letter level. In separate conditions, the subjects were required to count either the Fs, the Os, or both the Fs and the Os in the instances of the word OF. Specifically, if subjects miss the Fs because they miss the OFs or because they cannot easily partition the unit OF into its constituent letters, then detection of Os should be equally difficult. Both the redundancy and unitization hypotheses would predict failures on the Os as well as on the Fs. On the other hand, if subjects do detect the Os, then they can process the word at a letter-by-letter level and a subsequent attempt to detect the Fs should be successful. Three variations in the letters to be detected were used to test these hypotheses: In two conditions, the subjects always were to detect the same letters on each of three test trials (i.e., F-F-F or O-O-O), and in the third condition, the subjects were to detect different letters on each trial. Specifically, in this condition (F-O-F), Fs were to be detected on the first trial, Os on the second, and Fs again on the third.

A second issue addressed in Experiment 2 was that of letter and word shape and the particular format of the standard statement of Experiment 1. Wheeler (1970) argued that word shape is an effective cue in reading, such that when all letters are capitalized, as in Experiment 1, the Fs are less distinctive than they are in lower-case form. To test this possibility, F detections with upper- and lowercase versions of the statement were compared.

Method

The design was a 2 x 3 between-subjects factorial combination of the two variables of letter case (upper vs. lower) and the letters detected on the three experimental test trials (same letters as Fs or Os, or different letters, Fs and Os). However, of the data for the six subject groups, the data for the uppercase, same-letter condition (F-F-F) were obtained from the control group of Experiment 1, rather than by running another large group of subjects. The remaining groups had the following sample sizes: O-O-O (51), F-O-F (52), f-f-f (54), o-o-o (52), and f-o-f (56). The procedure was identical to that used in the control group of Experiment 1; separate requests to count the number of letters in the statement projected onto a screen were made on booklet pages. Different booklets for the experimental groups were distributed randomly to class members. No feedback was given during the brief session.

Results and Discussion

The percentages of letters detected are presented in Figure 2. The contrast between the slow, linear gains made over trials by the same-letter conditions and the dramatic course of letter detections in the different-letter conditions is immediately evident. It is obvious that, although the subjects in the latter groups (F-O-F

Figure 2. The percentage of letters detected on each of three test trials in each condition of Experiment 2. Conditions are designated by the particular letters detected on each of the test trials (e.g., F-O-F) and letter case of statement (e.g., F-O-F vs. f-o-f).

and f-o-f) demonstrated their attentiveness to the word OF on the second trial by making close-to-perfect detections of the four Os in the statement (only 27 of 432 were missed), their gains were short-lived. On the third trial, their detections of Fs were as poor as those of other subjects who counted Fs on both preceding trials. The data were subjected to 2 x 3 analyses of variance. Overall, the subjects who counted Os performed significantly more accurately than did those who counted both Os and Fs, who, in turn, performed significantly better than did those counting Fs alone [$F(2,395) \geq 132.93$]. As in Experiment 1, trials were a significant source of variability [$F(2,790) \geq 80.20$], but, as may be seen in Figure 2, this variable interacted with experimental conditions [$F(4,790) \geq 72.14$]. Finally, although the overall effect of letter case was nonsignificant, this variable did interact with trials and reflected the greater gains made over trials in the upper- than in the lowercase conditions. This interaction approached significance ($p < .10$) for the percentage-perfect measure and achieved significance in the percentage-letters-detected measure [$F(2,790) = 5.02$, $p < .01$]. Although these latter differences were small, their direction was unexpected. It appears, therefore, that the use of uppercase letters hinders reading sufficiently to actually enhance the detection of Fs.

In short, the results demonstrate that the failure of subjects to correctly detect Fs does not stem either from a failure to attend to the word OF or an inability to process the word at a letter-by-letter level: Letter detections of Os were close to perfect on the first trial for the same-letter conditions and on the second trial for the different-letter conditions. These results place considerable doubt upon those hypotheses that emphasize either the redundant or, at the level of letters, the unitized character of OF. These hypotheses were tested again in Experiment 3. Finally, the results demonstrated that the low detection rate of F in OF is not peculiar

to uppercase presentation: The even lower detection rates with lowercase presentation supports the view that the F-detection rates are a result of normal reading processes.

EXPERIMENT 3

On the basis of subject comments during debriefing after the first two experiments, it was clear that, of the six Fs in the statement, only those in the OFs were not detected. Nevertheless, it was important to demonstrate this point. In Experiment 3, a control group read the statement and circled instances of the letter F. To anticipate the results, whenever the subjects failed to circle one or more Fs, the Fs that were not circled were always located in instances of the word OF. Three other conditions were also included to test further the redundancy and the unitization hypotheses. To the extent that redundancy and unitization are products of the use of short, high-frequency words like OF, then letter-detection failures should also occur on other two-letter, high-frequency words. Indeed, Healy and Drewnowski have repeatedly made this point. However, the basic stimulus materials in their research have been prose passages (or transformations thereof) rather than single statements. Thus, an analysis of letter detections in another short, high-frequency function word would be valuable when a single statement is used. In Experiment 3, letter detections of N in instances of the word ON were used for comparison. The Kučera and Francis (1967) norms reveal that ON occurs 6,742 times per million words and is ranked 16th in frequency. If word frequency is a major contributing factor to letter-detection failures in single statements, the Ns should be frequently missed. The statement was: **NUMBERED NOVELS ARE CROWDED ON THE SHELVES BY THE PERSONAL PICTURES ON THE RACKS ON THE WALLS.** In addition to this N condition, two other conditions were used to test hypotheses about the subjects' detection criteria in their letter searches. First, it can be argued that the F in OF is not detected because subjects easily find the three Fs in the content words **FINISHED**, **FILES**, and **SCIENTIFIC** and then terminate the search before finding any others. In short, subjects readily accept three Fs as being an adequate answer to a peculiar question. Because of redundancy, however, the Fs in instances of OF are missed. If, on the other hand, there were no other Fs in the statement, then subjects would not terminate their search as quickly and, hence, should detect more of the Fs in instances of the word OF. To test this possibility, a statement was constructed in which the only Fs present occurred in three instances of the word OF. The statement was: **TARNISHED TILES ARE THE RESULT OF YEARS OF STEADY SCOURING COMBINED WITH THE DETE-RIORATION OF YEARS.** This condition is hereafter referred to as the 3F condition.

A final condition explored a specific hypothesis

related to detection by phonetic recoding. Since the Fs in **FINISHED** and **FILES** are pronounced /f/ and occur early in the statement, subjects may quickly develop a set to scan their acoustic image only for /f/ sounds and ignore /v/ sounds. To test this possibility, the standard statement was reversed, such that the early pronunciations of F were as /v/; subjects in this reversed condition therefore would be expected to develop an alternative set. If this hypothesis had any merit, some of the Fs in the words **FINISHED**, **FILES**, and **SCIENTIFIC** would be expected to be missed. The statement in its reversed form was: **THE RESULTS OF YEARS OF SCIENTIFIC STUDY COMBINED WITH THE EXPERIENCE OF YEARS ARE FINISHED FILES.**

Method

A total of 145 subjects served in four experimental conditions; the groups in these conditions ranged in size from 35 to 38. All subjects received booklets with a test statement written on each page and the instruction to circle the appropriate letters (Fs or Ns). However, as before, there were no other controls on the number of letter-detection attempts actually made by the subjects. Feedback was not provided.

Results and Discussion

Compared with simply counting Fs from the projected statement in the first two experiments, the circling activity did improve performance. In the standard statement, there was a gain of 25% in the percentage of subjects who detected all of the Fs on the third trial. Nevertheless, the task remained difficult, with fully one-half of the subjects performing at a less than perfect level after three test trials.

The percentages of Fs detected in the three instances of OF and the three Ns in the instances of ON are presented in Figure 3. No errors were made in the detections of the remaining Fs in **FINISHED**, **FILES**, and **SCIENTIFIC** or in the detection of the Ns in **NUMBERED**, **NOVELS**, and **PERSONAL**. To the extent that OF and ON may be treated as being similar high-frequency function words and as being relatively redundant in the statements, the detection of Fs stands apart as a unique and robust phenomenon.

Analysis of variance of the two dependent measures revealed main effects of groups [$F(3,141) \geq 7.00$] and trials [$F(2,282) \geq 5.14$, $p < .01$]. Newman-Keuls comparisons of the group means for the percentage-letters-detected measure revealed that the N condition differed significantly from each of the other conditions ($p < .01$), which did not differ from each other ($p > .05$). Inspection of the percentage-perfect measure revealed an interesting pattern of results. Specifically, all-or-none performances often occurred in the 3F condition, such that whereas a high overall percentage (69.3%) of the subjects detected all three of the Fs, the remaining 30.8% usually missed all three. These latter subjects brought down the average percentage of letters detected for the group in line with that of the subjects in the standard condition, who instead, more frequently, detected one or two of the Fs. In the reversed condition,

Figure 3. The percentage of letters detected on each of three test trials in each condition of Experiment 3.

a larger percentage of subjects (48.2%) than in the 3F condition missed all three Fs and thus brought the average percentage of letters detected in this condition to a level lower than that in the standard condition. Hence, the early positioning of the instances of OF in the statement produced an even poorer performance than that for the late positioning. Taken together, the effects of these manipulations indicate that the structure of the statement does have some bearing upon performance and again implicates redundancy as one basis of the detection failures.

In summary, the results of Experiment 3 showed, first, that the activity of circling letters, as compared with counting alone, improved performance. Second, the detection of F in OF depended to some degree upon the availability of other instances of the letter F in the statement. Thus, the subjects apparently altered their detection criteria when task difficulty increased. It would be valuable to explore this relationship between the ease of detecting Fs (as reflected in, for example, latency measures) and the availability of other instances of Fs in words other than OF. Third, the ease with which the subjects detected the N in the instances of ON demonstrates that, for this high-frequency function word, letter-by-letter analysis is possible and questions the generality of the unitization hypothesis. Finally, the hypothesis that a phonetic set in favor of /f/ pronunciations was engendered by a particular wording of the standard statement was not supported; that is, detection failures did not depend upon the early positioning of /f/ pronunciations of the letter F.

EXPERIMENT 4

The results of the first three experiments provided no support for the unitization hypothesis and demonstrated that although redundancy is implicated in the explanation of the F-detection failures, it does not

appear to be the sole explanation. Whereas performance can be altered to some degree by interfering with the normal reading process, it is clear that simply getting people to pay more attention to instances of the word OF does not eliminate the detection failures. Indeed, it is the robustness of these failures across a variety of procedures that gives the phenomenon its special appeal.

As yet, a phonetic-recoding hypothesis that focused upon the atypical pronunciation of F in OF had not been tested. To do so properly would require other high-frequency function words in which the letter F was pronounced /f/ rather than /v/. Ideally, in such words the letter O should also precede F, as it does in OF. Although OFF satisfies these requirements, the doubling of Fs appeared to be overly distinctive. The word closest to OF in which F is pronounced /f/ is the function word IF. Therefore, as a test of the phonetic-recoding hypothesis, detections of F in IF and OF were compared. Kučera and Francis's count of 2,199 instances of IF per million words places it substantially lower in frequency than OF. However, in their ranking of 54,000 words, IF was placed 50th and its usage is 22 times more frequent than the commonly accepted value for high-frequency words of 100 occurrences per million. By these standards, IF is a word of extremely high frequency.

Because the pronunciation of F in OF depends upon the phonetic recoding of the letters O and F as a single syllabic unit, variables that alter the likelihood of this particular recoding should alter the likelihood of the detection of F in OF. One such variable is that of word spacing (normal spacing between words or unspaced). When the spaces between words are removed, identifications of the correct word units in the letter string are reduced such that the O and F are treated less frequently as a single unit for purposes of pronunciation. Such reductions are accompanied by increased mispronunciations of F as /f/. Accordingly, detections of F in OF should increase. Although correct segmentation of a letter string may implicate some type of phonological recoding beyond lexical access, it is unnecessary to postulate such recoding at this time. This experiment did not speak to a particular type of phonological recoding of all those codes that are possible (see Foss & Blank, 1980, and McCusker, Hillinger, & Bias, 1981).

Since there was some support in Experiment 3 for the redundancy hypothesis, it was tested once more by manipulating the predictability of the word OF in the standard statement. The variable chosen to effect these manipulations was that of word order (normal or scrambled syntax). With scrambled as opposed to correct syntax, the statement should have less meaningfulness and less redundancy without, presumably, the pronunciation of F in OF being altered. These two variables were combined factorially with the two sentence forms (standard OF and new IF statements) to

yield eight experimental conditions in a $2 \times 2 \times 2$ experimental design. It was predicted that the effects of the spacing variable would be larger than those of the word-order variable because pronunciation is more likely to be altered by the removal of spacing than by the scrambling of word order. Finally, it was predicted that neither word-spacing nor word-order variables would affect the detections of F in instances of IF, because under no circumstances would the F in IF ever be mispronounced /v/.

Method

Eight groups (each group = 42 to 50 subjects) were given three-page booklets and instructions identical to those given to the control group of Experiment 3. The subjects in all conditions circled instances of the letter F; six Fs were available in every condition.

Two basic statements were used: the standard statement, with three instances of the word OF (as described in Experiments 1-3), and a similar statement, with three instances of the word IF instead. This statement was of the following form: FINISHED FILES IF VALID AND IF COMBINED WITH SCIENTIFIC STUDY WILL YIELD RESULTS IF GATHERED OVER YEARS. Clearly, an attempt was made to construct a statement that was similar in form and length to the standard OF statement.

Each of the two statements was presented in four different formats, which corresponded to the factorial crossing of the word-order and word-spacing variables. The formats were: correct order, words spaced (CSP), scrambled order, words spaced (SSP), correct order, words unspaced (CU), and scrambled order, words unspaced (SU). The only spaces that occurred in the unspaced versions occurred at the end of the first line of type.

Results and Discussion

Figure 4 presents the percentage of Fs detected in the OF and IF words of the two statements. Because virtually no errors were made on the other three F words, only the data for the critical OF-IF comparison are presented here. Inspection of the figure immediately reveals

Figure 4. Percentage of letters detected on each of three test trials in each of the eight conditions of Experiment 4. Data are presented separately for the IF and OF statements.

a major difference between the two statements. Specifically, it may be seen that the word-order and spacing variables were effective with the OF but not with the IF statement. All variations in the IF statements produced results that were virtually identical and consistently close to perfect performances. Although the IF results may include ceiling effects, the use of highly similar statements within identical experimental settings minimizes the importance of such effects: The F was almost never missed in IF, but it was very frequently not detected in OF. The detection rate of the latter can be seen to be a function of the word-order and spacing variables. Analyses of variance of these data revealed main effects of the type-of-statement (OF vs. IF), spacing (spaced vs. unspaced), and word-order (correct vs. scrambled) variables [$F(1,361) \geq 17.70$]. Moreover, because the effects of the spacing and word-order variables depended to a large degree upon the statement read, two-way interactions of these variables with statement type were also significant [$F(1,361) \geq 4.86$, $p < .025$]. One unexpected result was the failure of a few subjects in the IF-CSP condition to detect a few of the Fs in instances of IF. However, as may be seen in Figure 4, the number actually missed was small and did not differ significantly from any of the other IF conditions.

Two observations should be made about the four variations of the OF statement. First, it is clear that the effect of the spacing variable was larger (86.6% vs. 56.6% for the unspaced and spaced versions, respectively) than that of the word-order variable (81.7% vs. 62.6% for scrambled and correct versions, respectively). Indeed, with no spacing between words and scrambled word order, F detections in OF approached those of the IF statement. Since appropriate segmentation is provided for the subjects in the normal spacing conditions, the F in OF is usually pronounced /v/ and, as a result, the word order is of less importance. In short, when the cues for word segmentation are minimized, the F in OF is more likely to be pronounced /f/ and, therefore, to be detected. The second observation supports this interpretation. That is, in the two unspaced versions of the OF statement, the percentage letters detected actually declined from the second to the third test trial, whereas performance in the spaced conditions increased. That this was a reliable effect is supported by a significant three-way interaction among trials, statement, and spacing [$F(2,722) = 3.41$, $p < .05$]. A reasonable explanation of this effect may be that with repeated exposures to what may first appear to be a haphazard string of letters, subjects learn to segment into a sequence of words. Such segmentation would be accompanied by increased frequency of /v/ pronunciations of F in OF. The extent of this decline is perhaps underestimated because subjects would probably be hesitant to report having detected fewer Fs from one trial to the next.

The surprising outcome was the effect of word order on the detections of F in OF. The variable of word order

was assumed to affect the redundancy or predictability of the word OF such that, when highly predictable, OF would be missed. The difficulty with this interpretation, of course, is that we should then also expect the F in IF to be missed when word order is correct in the IF statement. At the least, there is no *a priori* reason for IF to be detected much more frequently than OF. Again, if missed Fs reflect missed IFs, the instances of IF were virtually never missed. In short, redundancy appears to be important for OF but not for IF. Because this seems unlikely, an alternative explanation of these results may lie in the subjects' activities during the letter-detection task. When the subjects read the statement for comprehension, instances of the letters O and F were no doubt read as OF and the letters I and F, as IF. However, with scrambled word order, subjects may not as frequently read for comprehension and, instead, engage in a pure letter-detection task. Drewnowski and Healy (1977) have suggested this possibility as an explanation of improved letter detections with alterations in the format of prose passage materials (e.g., scrambling or arranging in a list format). If this is the case, pronunciation would be affected by the redundancy, as well as by the word-spacing, manipulations. That is, when treated as separate letters, the F in OF becomes /f/ but the F in IF remains /f/: hence, the lack of effect of word order in the IF statement conditions. It is important to note, however, that in the scrambled-order, spaced OF condition (SSP), performance was still far from perfect and was consistently lower than that for either of the unspaced conditions.

EXPERIMENT 5

The F-detection rates in Experiment 4 were affected primarily by the retention or deletion of normal spacing between words and secondarily by the predictability of the statement. That is, since there was a significant superiority of the scrambled over the normal word order for the OF statement, predictability or redundancy of the statement apparently did play some part in the detection failures of F. The results of the 3F and reversed conditions in Experiment 3 also suggested some role of redundancy. In the final experiment, the format of the OF statement was altered in such a way as to disturb normal left-to-right reading habits and, presumably, to reduce the influence of redundancy to an even greater degree. According to Drewnowski and Healy (1977), the presentation of material in a vertical or list format rather than in a left-to-right format should eliminate processing at levels higher than the word. In short, redundancy should be greatly reduced, and, if redundancy is one basis of the detection failures of F in OF, few Fs should be missed and the subjects' task should resemble one of letter detection only. Experiment 5 compared the rates of detection failures between a standard, horizontal presentation and a list presentation. The question asked was whether such an alteration

Table 1
Percentages of Fs Detected (in OF) for the Standard
Horizontal and Vertical (List) Formats
on Each of Three Test Trials

	Trial Number		
	1	2	3
Horizontal	41.4	47.3	51.4
Vertical	69.7	74.7	76.8

in format would match or outweigh the major role of phonetic recoding suggested in Experiment 4.

Method

The standard OF statement was typed in a list format, one word to a line, vertically aligned on the left side. As before, the subjects ($n = 33$) received instructions to circle each instance of F in the statement on each of three booklet pages. In place of collecting data from a separate group of subjects, the data obtained in the CSP condition of Experiment 4 ($n = 50$) was used as a control condition with which the vertical format could be compared.

Results and Discussion

Because the Fs in the words FINISHED, FILES, and SCIENTIFIC were virtually never missed, only the data for the three instances of OF were analyzed. These are presented in Table 1 for the standard and list formats of the statement. Inspection reveals the improved, but far from perfect, performance in the list, compared with that in the horizontal, condition. Significantly greater percentages of these subjects achieved perfect scores and, on average, detected more Fs than did the subjects in the horizontal condition [$F_s \geq 7.85$, $p < .01$]. Also, when compared with the SSP condition of Experiment 4, the list format is seen to enhance performance to a greater degree. In short, redundancy plays a role in the detection failures, but its contribution appears to be no larger than that of phonetic recoding. Furthermore, it is possible that with scrambled-word-order and list-format presentations, the nature of subjects' predominant activities changes from one of reading to that of a letter-detection task alone. In this case, the word OF may not invariably be read as a word, and, if so, F may be pronounced as /f/ rather than as /v/. Taken together, the results of both Experiments 4 and 5 suggest that whenever the letters O and F are read as a unit, the probability of a detection failure is increased.

GENERAL DISCUSSION

The results of these five experiments point to the importance of response units, as contrasted with perceptual units, in reading. The primary conclusion of the results is that the subjects in these letter-detection tasks frequently scanned their acoustic images, rather than their visual images, of what they had read for instances of the letter F. Although pronunciation of F as /v/

depends upon the integration of O and F as OF, the explanation of the letter-detection failures does not reside in Drewnowski and Healy's original unitization hypothesis (e.g., Drewnowski & Healy, 1977; Healy, 1976, 1980). This hypothesis assumed that the level of analysis in reading by skilled readers may be higher than single-letter units and that, as a result, detection failures occur because of subjects' failure to completely process a word at its lowest level, in this case, that of letters. Once letters have been identified as a word, processing of the letters is terminated, and the next unit in the text is identified. Although Healy and Drewnowski's previous work supports the unitization hypothesis for other very common words, the present subjects' abilities to easily detect the O in OF, the F in IF, and the N in ON argue against it as an explanation of the detection failures in OF. Indeed, it is reasonable to question whether the unitization hypothesis is even applicable to two-letter words.

Instead, the results of the present experiments point to phonetic recoding as a major factor and to redundancy as a lesser factor in the detection failures of F. In particular, subjects appear to miss the F in OF largely because of its atypical or nonmodal pronunciation. That is, the phonetic identity of F as /f/ is altered within the word OF, and, because OF is the only word in English for which this occurs, the subjects' past experiences have not prepared them for this detection. Other researchers have made this same point; for example, Locke (1978) demonstrated the greater difficulty of letter detections in words that have atypical or nonmodal pronunciations than in those that have modal pronunciations of the target letters. Furthermore, in work completed with elementary school children, we have observed that the level of detection failures of F in OF changes rapidly in the early grades and approaches that of adult readers by the end of the third grade, at about age eight years (Read, Cross-Calvert, & Krushel, Note 2). Because OF is also the second most frequent word in English, the phonetic effect suggested herein appears, at first blush, rather paradoxical. That is, although the pronunciation of F as /v/ is atypical across words, it may actually be most representative of all pronounced occurrences of F in English. Why then, would subjects be misled by such frequent pronunciation? Perhaps what we have observed in this instance is an interaction between redundancy and phonetic recoding such that skilled readers are unaware of F's /v/ pronunciation because OF is generally ignored by virtue of its high-frequency and function-word status. A suggestion for future research, then, is the further investigation of phonetic recoding via the study of other words that contain nonmodal phonemes.

Finally, the present results fit easily into what may be seen as a general and recent reemphasis upon phonetic factors in the reading literature. For example, Drewnowski and Healy (1982) argued in favor of a

combination of the unitization and phonetic-recoding hypotheses to account for results of some letter-detection studies. With some minor modification, the present results could likely be accommodated by this joint hypothesis of the reading process. According to this broader view, subjects scan a phonetically recoded version of the printed text. If the particular target phonemes searched for are available and are salient in such a code, they are usually detected. However, because syllables may be read as integrated units, some phonemic characteristics within syllables are not always identified, because they are not completely processed. In particular, whether or not letters in Drewnowski and Healy's experiments were detected depended upon the presence or absence of syllabic stress. When syllables were unstressed rather than stressed, more errors were made, and this effect was largest for high-frequency words. Thus, they argued in favor of a phonetic effect at the level of syllables. They further suggested that the initial syllable in a multisyllabic word is usually processed to the point of letter identification and that the phonetic effect of stress tends to be restricted to the subsequent syllables. The results of the present research may be interpreted as a demonstration of the extension of phonetic factors to a monosyllabic high-frequency word as well. Second, other recent presentations of models of reading emphasize a dual access of both visual and phonological mediating information to the internal lexicon (e.g., McCusker et al., 1981). One assumption common to these models that is relevant to the present research is that access is visual for high-frequency words but is phonological for low-frequency words. To the extent that words and the letters within those words may follow similar routes to the lexicon (an issue not addressed in the literature), both the F in OF and the F in IF should gain access via visual information. However, since their probabilities of letter detection have been demonstrated to be markedly different, it is unlikely that access for both is gained through visual information about these letters. Either they both gain access via phonological recoding or, the view favored here, both forms of access are available to each. In any case, these results, like those of Drewnowski and Healy (1982), place new emphasis upon the interdependence of visual and phonetic factors in reading.

REFERENCE NOTES

1. Schindler, R. M., & Jacobs, P. I. *What do we see when we read?* Paper presented at the annual meeting of the Eastern Psychological Association, New York, April 1976.
2. Read, J. D., Cross-Calvert, S. E., & Krushel, L. *The detection of Fs in the word OF: Developmental findings*. Unpublished paper, 1983.

REFERENCES

- CORCORAN, D. W. J. An acoustic factor in letter cancellation. *Nature*, 1966, 210, 658.

- COREN, S., & GERGUS, J. S. *Seeing is deceiving*. New York: Erlbaum, 1978.
- DREWNOWSKI, A. Detection errors on the word *the*: Evidence for the acquisition of reading levels. *Memory & Cognition*, 1978, 6, 403-409.
- DREWNOWSKI, A., & HEALY, A. F. Detection errors on *the* and *and*: Evidence for reading units larger than the word. *Memory & Cognition*, 1977, 5, 636-647.
- DREWNOWSKI, A., & HEALY, A. F. Missing *-ing* in reading: Letter detection errors on word endings. *Journal of Verbal Learning and Verbal Behavior*, 1980, 19, 247-262.
- DREWNOWSKI, A., & HEALY, A. F. Phonetic factors in letter detection: A reevaluation. *Memory & Cognition*, 1982, 10, 145-154.
- FOSS, D. J., & BLANK, M. S. Identifying the speech code. *Cognitive Psychology*, 1980, 12, 1-31.
- HEALY, A. F. Detection errors on the word *the*: Evidence for reading units larger than letters. *Journal of Experimental Psychology: Human Perception and Performance*, 1976, 2, 235-242.
- HEALY, A. F. Proofreading errors on the word *the*: New evidence on reading units. *Journal of Experimental Psychology: Human Perception and Performance*, 1980, 6, 45-57.
- HEALY, A. F. The effects of visual similarity on proofreading for misspellings. *Memory & Cognition*, 1981, 9, 453-460.
- JUST, M. A., & CARPENTER, P. A. A theory of reading: From eye fixations to comprehension. *Psychological Review*, 1980, 87, 329-354.
- KUČERA, H., & FRANCIS, W. N. *Computational analysis of present-day American English*. Providence, R.I: Brown University Press, 1967.
- LOCKE, J. L. Phonemic effects in the silent reading of hearing and deaf children. *Cognition*, 1978, 6, 175-187.
- MCCUSKER, L. X., HILLINGER, M. L., & BIAS, R. G. Phonological recoding and reading. *Psychological Bulletin*, 1981, 89, 217-245.
- RAYNER, K. Eye movements in reading and information processing. *Psychological Bulletin*, 1978, 85, 618-660.
- SCHINDLER, R. M. The effect of prose context on visual search for letters. *Memory & Cognition*, 1978, 6, 124-130.
- VENEZKY, R. L. *The structure of English orthography*. The Hague: Mouton, 1970.
- WHEELER, D. D. Processes in word recognition. *Cognitive Psychology*, 1970, 1, 58-85.

NOTE

1. I am not aware of the original source of this statement; however, on the basis of comments from colleagues, it seems to be reasonably well known. In my case, however, I thank Roger Barnsley for having noted it on a Wisconsin motel business card and for having brought it to my attention. After the present experiments had been completed, I obtained a reference to R. M. Schindler and P. I. Jacobs, who used the identical statement in an investigation of the effects of prose context on letter-detection errors.

(Manuscript received December 22, 1983;
revision accepted for publication April 11, 1983.)