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Word Recognition Inside Out and Outside In

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Predictions for word recognition latencies were generated for the independent parallel model of word recognition based on letter-naming latencies in two display conditions. In one condition, the inside two letters of four-letter words were presented 50 msec in advance of the presentation of the whole word, whereas in the other condition, the outside two letters were presented 50 msec in advance. The model predicts that the two conditions should yield roughly equal recognition latencies, but in each of four experiments the prior presentation of the outside letters led to faster recognition. The implications of these results for the family of parallel models (nonindependent as well as independent) are discussed.

Since the 19th century when Cattell (1886) demonstrated that short familiar words could be read in brief exposures as readily as could single letters, students of reading have entertained the notion that the individual letters of a word are processed in parallel (cf. Huey, 1908/1968; Massaro, 1975; Reicher, 1969; Wheeler, 1970; Woodworth, 1938). Nevertheless, to date much of the theoretical research in word recognition has been motivated by left-to-right serial models, largely because such models lend themselves so readily to empirical testing. However, many researchers have judged the serial models to be less than satisfactory and have opted for parallel models as the logical alternative (Massaro, 1975; Theios & Muise, 1977; Travers, 1973, 1974).

Unfortunately, parallel models are not so easily testable as the serial models because of the infinite variety of possible interdependencies among the simultaneous processing units. It is difficult for parallel models as a class to generate strong, testable predictions, since some type of parallel model can be constructed to account for virtually any pattern of results. Indeed, by combining certain underlying distributions of processing times and certain interdependencies among the processors, we can construct parallel models that yield behavior that is indistinguishable from that of left-to-right serial models (Townsend, 1971, 1972). This ability of certain parallel models to mimic serial models makes it practically impossible to design experiments that are able to rule out one class of models or the other. Thus, while the family of parallel models is presently popular in psychology, the ability of parallel models (as a class) to generate strong, testable predictions is limited. Parallel models seem to have their following not so much because of the preponderance of evidence in their favor but because of the lack of controverting evidence.

However, one parallel model that does lend itself to empirical testing is the independent parallel model. The independent parallel model is of special importance within the broader class of parallel models because it is the archetypical parallel model, it is the simplest parallel model, and it carries the fewest assumptions.

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The independent parallel model accurately describes subjects' ability to detect target letters embedded in rectangular (Eriksen & Lappin, 1967; Gardner, 1973; Wolford, Wessel, & Estes, 1968) and circular (Eriksen & Spencer, 1969) displays as well as subjects' recognition latency in detecting such target letters (Wolford et al., 1968). Moreover, it accounts for the data on subjects' recognition latency in determining whether the elements of a display are physically identical or not for geometric forms in random configurations (Donderi & Case, 1970; Donderi & Zelnicker, 1969), for letters and numerals in circular displays (Egeth, Jonides, & Wall, 1972), and for letters in horizontally displayed strings (Beller, 1970).

Nevertheless, more recent evidence suggests that the processing of letters in words is not done independently. The seminal experiments of Reicher (1969) and Wheeler (1970) compared subjects' abilities to identify letters in words and the same letters in isolation. In the Reicher-Wheeler paradigm, the letter K might be presented and the subject subsequently asked to decide whether D or K had been presented, or the word WORK might be presented and the subject asked to decide whether D or K had been the fourth letter. Since both D and K complete a word, Reicher and Wheeler believed that they had controlled for the potential contribution of (higher order) redundancy provided by the other letters of the word. Reicher (1969) and Wheeler (1970) found that in a tachistoscopic glimpse, subjects are better able to recognize a letter in a word than a letter in isolation or in a nonword, a phenomenon that has come to be known as the *word superiority effect*.

However, while tachistoscopic recognition may not be the best paradigm for studying the processes of word recognition (since the visual information presented to the subject is so severely restricted), the findings of Reicher and Wheeler have been attacked on other grounds. Thompson and Massaro (1973) argued that the control for redundancy employed by Reicher and Wheeler is not adequate, especially if whatever partial information the subjects might have gleaned about the target letter cannot be preserved long enough to permit comparison with the response alternatives. They maintained that the appropriate way to control for redundancy is to present the response alternatives prior to the presentation of the stimulus. When they did this, the word superiority effect disappeared.

But even this result is the subject of some disagreement. Whereas Bjork and Estes (1973), Estes (1975a, 1977), Estes, Bjork, and Skaar (1974), and Massaro (1973) also found no word superiority effect when the response alternatives were presented in advance, Carr, Lehmkuhle, Kottas, Astor-Stetson, and Arnold (1976), Spector and Purcell (1977), and Reicher (1969) himself did find the effect. Thus, the tachistoscopic evidence that bears on the independence–nonindependence of the recognition of letters in word recognition remains inconclusive. (See Baron, 1978, for an alternative interpretation of these results.)

Other evidence against the notion of independence in the independent parallel model comes from visual matching studies in which subjects' recognition latencies in deciding whether a string of letters are the same or different are measured. Both Eichelman (1970) and Pollatsek, Well, and Schindler (1975) found that words could be compared faster than nonwords even when the strings differed only in the case of a single letter (Pollatsek et al., 1975). Such a pattern of results would be difficult for an independent parallel model to accommodate. However, it remains unclear how applicable such results are to the process of word recognition. The effects found in the visual matching paradigm might reside in a comparison process unique to that paradigm rather than in any process concerned with the formation of a visual representation. Thus, such evidence cannot remove the independent parallel model from the list of candidate models of word recognition.

When the independent parallel model is applied to word recognition, it predicts that the time required to apprehend any four-letter word will be described as follows:

$$A_4 = \max(t_1, t_2, t_3, t_4), \qquad (1)$$

where t_1, t_2, t_3, and t_4 are random variables representing the times required to recognize the first, second, third, and fourth letters, respectively. In this particular independent parallel model, it is assumed that all of the letters must be apprehended before the word can be recognized. Hence, the model is analogous to a horse race wherein the time taken to run the race is determined by the slowest horse.

Under the model, the time to initiate articulation (naming latency) of a four-letter word would be described as

$$T_4 = \max(t_1, t_2, t_3, t_4) + t_0, \qquad (2)$$

where t_0 is a "wastebasket" variable that includes the time taken by all of the processing subsequent to apprehension that might occur (such as accessing the mental lexicon) as well as the time required to initiate the response. The expected value of the naming latency would be

$$E(T_4) = E[\max(t_1, t_2, t_3, t_4)] + E(t_0). \qquad (3)$$

Now

$$E[\max(t_1, t_2, t_3, t_4)] = \int_0^\infty [1 - \prod_{i=1}^{4} F_i(t)]dt, \qquad (4)$$

where F_1, F_2, F_3, and F_4 are the distribution functions that correspond to t_1, t_2, t_3, and t_4, respectively (Mood, Graybill, & Boes, 1974). That is, $F_i(t)$ is the probability that processing of the ith element will be completed before time t. Thus, if one can obtain estimates of the distributions that underlie t_1, t_2, t_3, and t_4, one can derive predictions about recognition latencies for the independent parallel model.

In Experiments 1 and 2, estimates of the distributions of t_1, t_2, t_3, and t_4 were made in order that such predictions could be derived for four-letter words presented in two conditions in which two of the four letters were "primed"; that is, they were presented in proper position prior to presentation of the whole word. In one condition, the inside-out (I-O) condition, the inside two letters were presented 50 msec in advance of the presentation of the remaining outside letters (whose appearance completed the word). In the other condition, the outside-in (O-I) condition, the outside letters preceded the presentation of the inside letters by 50 msec. By the horse race analogy, in each of these two conditions, two of the "horses" were given 50-msec head starts. In general, this letter-priming technique has been shown to have a facilitative effect on word recognition (Manelis & Atkinson, 1974; Forster & Gartlan, Note 1).

In Experiments 1 and 2, subjects named the individual letters of four-letter words presented in the I-O and O-I conditions, and the resulting distributions of naming times were used to estimate the parameters of the distributions underlying t_1, t_2, t_3, and t_4. Now clearly, the mean letter-naming times will be far greater than the actual means for t_1, t_2, t_3, and t_4, since they will include time consumed by the response component. However, it is assumed that as long as the same letters are named in each of the four positions, the mean of the response component will be the same for each distribution, and hence the *differences* among the means for the letter-naming latencies will be accurate estimates of the differences among the means of t_1, t_2, t_3, and t_4. At the same time, the variances of the distributions of letter-naming times will also overestimate the variances of the distributions of t_1, t_2, t_3, and t_4, since the response component will also contribute some variance of its own to the variance exhibited by each letter-naming latency. The correct variances of t_1, t_2, t_3, and t_4 must lie somewhere between zero and the variances exhibited by their respective distributions of letter-naming times. However, it is not clear just where within that range they might actually lie. Hence, it will be necessary to treat the variances as a free parameter in predicting word-naming latency.

Experiment 1

Method

Subjects. Fourteen undergraduate and graduate students at the University of Texas at Austin served voluntarily as subjects. Seven were male and seven were female. As in all of the experiments, all subjects claimed to be native speakers of English and to have normal or corrected-to-normal vision.

Stimuli. The stimulus items were four-letter English words collected in sets of four such that a target letter appeared in each of the four letter positions flanked by the same neighbors. For example, one such set is SLAM, LAME, AMEN, and MEND. In this set, the letter M appears in each position and is always flanked by A on the left or E on the right, or both. Twenty-one such sets were used, and they are listed in Table A1 of the Appendix.

Apparatus. Stimulus words were presented in uppercase letters on a Tektronix Type 601 Storage Display scope, controlled by a Digital Equipment Corporation PDP 8/I computer, which also randomized the order of presentation of the items for each subject. Each four-letter word measured 1.8 cm across, and at the viewing distance of 103 cm it subtended a visual angle of 1.0°. A throat microphone and a Grason-Stadler Voice-operated Relay signaled to the computer when the subject made a response. Subjects initiated a trial by depressing a foot button.

Procedure. A trial began with the appearance on the screen of an arrow, roughly the size of a character, pointing upward. After 500 msec, the computer began printing a word above the arrow such that the target letter was directly above the arrow. The subjects were instructed to name the letter above the arrow as quickly as possible. Each of the four words in each of the 21 stimulus sets was presented in the I-O and O-I condition as well as in a whole-word control condition, in which all of the letters were presented simultaneously. Thus, the subject named the same 21 letters in all four letter positions in three conditions.

Timing began when all of the letters of the word appeared on the screen and ended when the subject's articulation tripped the relay. The subject's response terminated the display.

Results

The mean reaction times (RTs) for the four letter positions in the three display conditions are listed in Table 1. In addition, for the resulting distributions of RTs for each subject in the I-O and O-I conditions at each letter position, a mean and a standard deviation were calculated. For each such pair (eight pairs per subject) of mean and standard deviation, three additional pairs were computed. Each mean was paired with a value of 75%, 50%, and 25% of its corresponding standard deviation. The resulting pairs of parameters were then treated as the means and standard deviations of normal distributions, and Equation 4 was solved four times for each subject for both the I-O and the O-I conditions. Finally, a prediction was computed for each subject in each condition on the assumption that there was no variance in the underlying distributions; that is, the predicted RT for each subject in each condition was simply the longest among the means for the four letter positions. The mean predicted word-naming latencies for the 14 subjects for the two conditions at each of the five standard deviation levels are listed in Table 2.

All of the predicted differences between the I-O and the O-I condition are small. None approaches significance.

Table 1
Mean Response Latencies (in msec) at the Four Letter Positions for the Three Display Conditions in Experiment 1

Display condition	Letter position 1	2	3	4
Whole word	477	512	512	497
Inside out	478	468	475	490
Outside in	422	489	499	447

Table 2
Mean Word-Naming Latencies (in msec) in Experiment 1 as a Function of the Proportion of Total Estimated Standard Deviation

Display condition	Proportion of total standard deviation (%) 100	75	50	25	0
Inside out	544	529	514	502	495
Outside in	540	527	513	506	501
Difference	4	2	1	−4	−6

Note. Latencies were predicted by the independent parallel model based on the observed distributions of letter-naming latencies in Experiment 1.

Discussion

The mean response times at the four letter positions (Table 1) in the whole-word condition exhibit the classic serial position curve for ease of letter recognition: The outside letters are easier to apprehend than the inside letters (Estes, Allmeyer, & Reder, 1976; Mason, 1975). This phenomenon is most likely the result of the greater lateral masking of the inside letters, which are flanked on two sides, as compared with the outside letters, which are flanked on only one side (Townsend, Taylor & Brown, 1971; Wolford & Hollingsworth, 1974).

In the I-O condition, the inside letters showed something less than the expected 50-msec benefit of priming (44 msec for the second letter and 37 msec for the third letter). This may reflect the fact that the appearance of the outside letters in the I-O condition may have a metacontrast effect on the inside letters (Weisstein, 1972; Werner, 1935) that makes their apprehension more difficult than in the whole-word display.

In the O-I condition, the effects of the 50 msec of priming for the outside letters led to roughly 50 msec of improvement in recognition latency (55 msec for the first letter and 50 msec for the fourth letter). At the same time, priming of the outside letters led to some improvement in the recognition latencies of the inside letters (23 msec for the second letter and 13 msec for the third letter), which may be the result of a release from lateral masking caused by a paracontrast (Weisstein, 1972) inhibition of the outside letters by the inside letters, which in turn would make the inside letters easier to apprehend than in the whole-word display.

Nevertheless, most germane to the present discussion are the results of Experiment 1 (given in Table 2), which indicate that the independent parallel model predicts that the I-O condition and the O-I condition should produce roughly equal naming latencies. Clearly, one cannot make any inference from the results of Experiment 1 about the absolute value of the predicted word-naming latencies for the I-O and O-I conditions based on the letter-naming latency data collected in Experiment 1. However, since the underlying distributions used to generate the predicted latencies in Table 2 are normal (where the mean and standard deviation can be manipulated independently of each other), the differences among the means of distributions of naming times should accurately reflect the differences in the means of the distributions that underlie t_1, t_2, t_3, and t_4, and hence provide accurate predictions of the difference between the I-O and O-I conditions (for a given standard deviation value).

Interestingly, the amount of standard deviation assumed to underlie the distributions of t_1, t_2, t_3, and t_4 seems to have very little effect on the predicted difference between the I-O and O-I conditions, the difference varying +4 and −6 msec. However, the size of the difference does appear to be an orderly, monotonic function of the percentage of standard deviation used such that the lower the standard deviation, the greater the predicted perceptual advantage for the I-O condition.

It should be noted that several subjects reported experiencing severe response competition when faced with the task of naming one letter in the midst of others. The target letters in Experiment 1 were embedded in words in order to provide subjects with the opportunity to make use of whatever information from intraword context they might ordinarily use. However, in the event that this attempt at maximizing the ecological validity of Experiment 1 somehow distorted the estimates, we conducted Experiment 2.

Experiment 2

Method

Twelve subjects from the same population served as subjects. Of the 12, six had served in Experiment 1. The stimulus "words" were fields of three dollar signs ($) and one letter, the target letter (e.g., A$$$, $A$$, $$A$, $$$A). Each of the 26 letters of the alphabet was used in each of the four letter positions and in each of the three conditions. Otherwise, Experiment 2 was exactly like Experiment 1.

Results

The mean RTs at the four letter positions for the three display conditions are listed in Table 3. Computations identical to those performed on the data of Experiment 1 were performed on the resultant means and standard deviations of Experiment 2. The mean predicted word-naming latencies for the two conditions at the five standard deviation levels are presented in Table 4. Again, all of

Table 3
Mean Response Latencies (in msec) at the Four Letter Positions for the Three Display Conditions in Experiment 2

Display condition	Letter position			
	1	2	3	4
Whole word	452	455	455	451
Inside out	440	386	391	435
Outside in	386	436	446	384

Table 4
Mean Word-Naming Latencies (in msec) in Experiment 2 as a Function of the Proportion of Total Estimated Standard Deviation

Display condition	Proportion of total standard deviation (%)				
	100	75	50	25	0
Inside out	476	465	455	447	443
Outside in	477	467	458	452	449
Difference	−1	−2	−3	−5	−6

Note. Latencies were predicted by the independent parallel model based on the observed distributions of letter-naming latencies in Experiment 2.

the predicted differences between the I-O and O-I conditions are small, and none even approaches significance.

Discussion

Overall, the mean letter-naming latencies of the subjects in Experiment 2 were considerably faster than those in Experiment 1, probably because of the reduced response competition for target letters in fields of dollar signs compared with letters in words. In addition, the letter-naming times in the whole-word condition (Table 3) showed virtually none of the inverted-U-shaped serial position effect found in Experiment 1. This suggests that the dollar signs provided less lateral masking of the target letters than did the adjacent letters used in Experiment 1. It is not clear from these data whether this is the result of the dollar signs' placing a smaller demand on low-level feature analyzers or their providing less competition for higher-level "letter detectors."

In the letter-priming conditions, all of the primed letters showed more than 50 msec of facilitation. In the I-O condition, the second letter was 69 msec faster than it was in the whole-word condition, and the third letter was 64 msec faster. In the O-I condition, the first letter was 66 msec faster and the fourth letter was 67 msec faster. Surprisingly, even the unprimed letters in the I-O and O-I conditions were faster than they were in the whole-word condition (by 9–16 msec).

Nevertheless, Experiment 2 shows the same absence of any sizable predicted difference between the two experimental conditions that was found in Experiment 1. Experiment 2 also showed a small but orderly effect of the amount of standard deviation assumed. Again, as the standard deviation percentage decreased, the predicted advantage for the I-O condition increased monotonically. Thus, it would appear that the independent parallel model predicts no difference in the recognition latency for four-letter words in either the I-O or the O-I condition. Moreover, this prediction holds, for practical purposes, across the range of possible standard deviations.

To test the predicted equality of the I-O and O-I conditions derived from Experiments 1 and 2, we conducted the following four experiments.

Experiment 3

Method

Subjects. Fourteen graduate students and faculty members in the Psychology Department at the University of Texas at Austin served as subjects. Ten were male and four were female, and all served voluntarily. Seven had also served as subjects in Experiment 1 or 2.

Stimuli. Fifty common four-letter words beginning with the letters *a, c, e, g, k, i, o, s, t,* or *w* were chosen. These letters were chosen because their pronunciation in word-initial position cannot be uniquely determined without knowledge of the second letter, and thus subjects would be discouraged from beginning their naming based only on the first letter (which is presented 50 msec earlier in the O-I condition than in the I-O condition). The median frequency (Kucera & Francis, 1967) of the items was 216.5, with a range of 1 to 10,595 occurrences per million.

Apparatus. The apparatus was the same as that used in Experiments 1 and 2.

Procedure. Upon entering the experimental chamber, the subject was given a list of the stimulus items to read. Since each word was presented three times in the course of the experiment, this procedure was necessary in order to reduce the variability in recognition latency between the first experimental presentation of an item and later presentations (Scarborough, Cortese, & Scarborough, 1977; McCusker, Note 2). Next, the lights were dimmed, and the subject was permitted 3 min. to adapt to the dim ambient illumination. The subjects were told to rest as often as they wished during the course of the experiment. Each item appeared in the two experimental conditions (I-O and O-I) and in the whole-word condition. In all conditions the naming latency was measured from the presentation of all of the letters to the initiation of articulation. There were 150 trials in all.

During the experiment, the experimenter sat in an adjacent booth and monitored an identical screen, recording any pronunciation errors made by the subject. Subjects were instructed to read the words aloud as quickly as possible while minimizing errors.

Results

The mean RTs for the means and medians for the 14 subjects in the three conditions are listed in Table 5. For the mean data, the main effect of condition is significant, $F(2, 26) = 35.43, p < .001$, as are two permissible orthogonal comparisons: The O-I condition is significantly faster than the I-O condition, $F(1, 13) = 21.14, p < .001$, and the two experimental conditions are significantly faster than the whole-word condition, $F(1, 13) = 55.82$, $p < .001$. For the medians, the main effect was again significant, $F(2, 26) = 24.95$, $p < .001$, the difference between experimental groups was significant, $F(1, 13) = 22.44$, $p < .001$, and the difference between the two experimental conditions and the whole-word control was also significant, $F(1, 13) = 27.54, p < .001$. Trials on which a subject either mispronounced a word or tripped the voice relay prematurely (with a cough or other extraneous noise) or responded too softly to trip the relay were counted as errors and not included in the data. The number of errors was small, averaging 2.57 per subject (1.7% of the trials). The modal number of errors per subject was 0, while two subjects made as many as 7 errors. The numbers of errors were not significantly different across conditions.

Discussion

The results of Experiment 3 are contrary to what is predicted by the independent parallel model. The model predicted no difference between the RTs for the two conditions, and in fact the RTs in the O-I condition were significantly faster. This result is in agreement with a finding of Forster and Gartlan (Note 1), who used a similar letter-priming technique and also found that "priming with the extremities of a word produces faster lexical decision times than priming with the interior" (Forster, 1976, p. 282). This finding is also consistent with the findings of Stanners, Forbach, and Headley (1971) and Stanners and Forbach (1973) that demonstrated the important role of initial and terminal letters and letter clusters in determining lexical decision latencies.

It also appears that the priming of certain letters of a word has the expected facilitative effect and is not particularly disruptive of the word recognition process, since the whole-word condition is significantly slower than either primed condition by a reasonable amount (i.e., somewhat less than the 50 msec of priming). Indeed, subjects who perform the task for the first time rarely notice any difference in the presentation of the words in the I-O, O-I, and whole-word conditions.

However, one uncontrolled and confounded variable in Experiment 3 is the number of possible response alternatives for an item given that its outside letters or its inside letters are known in advance. To check the effects of this variable, we examined a list of nearly all of the four-letter words that occur in English (see Experiment 4). For the stimuli used in Experiment 3, the average number of possible words, given the outside letters, was 11.52 ($SD = 6.77$) and the average number, given the inside letters, was 19.48 ($SD = 11.42$). Conceivably, the fewer response alternatives given the outside letters in the O-I condition could have led to a reduction of uncertainty, which in turn led to faster RTs in the O-I condition. Thus, the shorter naming latencies in the O-I condition compared with the I-O condition could have occurred as a result of a difference in the number of response alternatives and thus should not necessarily be considered evidence against the independent parallel model of word recognition. In an attempt to control for this factor, we conducted Experiment 4.

Table 5
Averages of Mean and Median Naming Latencies (in msec) for Experiment 3

	Display condition		
Measure	Whole word	Inside out	Outside in
Mean	490	479	463
Median	482	476	456

Experiment 4

Method

Subjects. Thirteen graduate students and faculty members at the University of Texas at Austin served voluntarily as subjects. Eight were males and five were females. Six had served in Experiment 1 or 2, and nine had also served in Experiment 3.

Stimuli. Items were chosen with the assistance of a CDC 6600 computer from a data bank consisting of all of the four-letter words in *Webster's New Collegiate Dictionary* (1970) known to at least one of three expert judges (the authors). A word was included if the number of possible four-letter words, given its two outside letters, was within 10% of the number of possible four-letter words, given its two inside letters. For example, the word EMIT shares its outside letters, E__T, with only EAST, EDIT, and EXIT. FMIT shares its inside letters, _MI_ with only AMIR, AMID, and OMIT. Thus EMIT was an acceptable stimulus item. Again, only words beginning with the letters *a, c, e, g, k, i, o, s, t,* and *w* were used. Thirty-seven such words exist, and they are listed in Table A2 of the Appendix.

Apparatus and procedure. The apparatus and procedure used were the same as those in Experiment 3, except that the whole-word condition was omitted. Thus, each subject saw each word twice, once in the I-O condition and once in the O-I condition.

Results

The average of the mean response latencies for the 13 subjects for the I-O condition was 473 msec and for the O-I condition was 452 msec. The difference was significant, $t(12) = 4.60$, two-tailed $p < .001$. The average of each subject's median response latency was 469 msec in the I-O condition and 446 msec in the O-I condition, $t(12) = 7.84$, two-tailed $p < .001$. As in the previous experiment, the number of errors was very low, less than 1% of the trials and not significantly different between conditions.

Discussion

The finding of Experiment 4 closely replicates, with a different set of materials, the major finding of Experiment 3. Again, the priming of the outside letters led to faster recognition, contrary to what was predicted by the independent parallel model. Nevertheless, it is possible that the control for response alternatives used in Experiment 4 was not the best possible. That is, the generation of the number of alternatives weighted each of the acceptable words equally. Recall that there were three words that shared either the same inside letters or the same outside letters as EMIT. However, the frequencies of these words are not similar. The sum of the frequencies (Kucera & Francis, 1967) for the three words with E__T as outside letters is 193, whereas the sum of the frequencies of the three words with _MI_ as inside letters is 18. Conceivably, this sort of discrepancy in the commonness of the response alternatives in the I-O and O-I conditions could have been responsible for the results of Experiments 3 and 4. Hence, in Experiment 5 we weighted the response alternatives according to their frequency of occurrence in the language in an attempt to better control for their accessibility in the mental lexicon.

Experiment 5

Method

Subjects. Fifteen subjects from the same pool of graduate students and faculty members were used. Eight had served in Experiment 1 or 2, and 13 had also served in Experiment 3 or 4.

Stimuli. The items were selected from a data bank that contained all the four-letter words listed in Kucera and Francis (1967) with their accompanying frequencies. For every word, the sum of the frequencies of all the other words that shared the same outside letters was tabulated as well as the sum of the frequencies of all the words that shared the same inside letters. We used the 29 words that began with *a, c, e, g, k, i, o, s, t,* and *w* and for which the smaller of these two sums was between 90% and 100% of the larger (see Table A3 of the Appendix).

Apparatus and procedure. The apparatus and procedure were identical to those used in Experiment 4.

Results

The average of the subjects' mean response latencies in the I-O condition was 471 msec and in the O-I condition was 449 msec. The difference is significant, $t(14) = 6.14$, two-tailed $p < .001$. The average median response latency for each subject was 463 in the I-O condition and 445 in the O-I condition, $t(14) = 5.58$, two-tailed $p < .001$. The incidence of errors was comparable to that in the previous two experiments. A total of 13 errors were made on the 870 trials (1.5%), and there was no significant difference in the number of errors between the groups.

Discussion

The results of Experiment 5 replicate those of Experiments 3 and 4 with yet a third set of materials and provide what should be the third strike against the independent parallel model. Moreover, the differences between the RTs for the I-O condition and the O-I condition for both the means and the medians for the three experiments are similar, averaging approximately 21 msec. Clearly, the magnitude of the effect found in Experiment 3 was not diminished by the use of the more restrictive material sets of Experiments 4 and 5.

However, all three experiments employed naming latency as the dependent measure. The use of words that begin only with the letters *a, c, e, g, i, k, o, s, t,* or *w* is a less than perfect means of ensuring that subjects will not initiate their response before processing the later letters of a word. For example, a word initial *c* may be pronounced /k/, /s/, /ch/, or not at all (*czar*), but for none of the chosen letters are more than four initial phones possible. Conversely, given the inside letters of nearly all of the stimulus items, any one of more than a dozen initial phones is possible. Moreover, Frederiksen and Kroll (1976) have shown that it is possible for word naming to be initiated without regard for the letters to the right of the initial cluster. It is thus possible that some sort of pronunciation uncertainty led to the slower RTs in the I-O condition. Thus, in order for the superiority of the O-I condition to prove damaging to the independent parallel model, it would have to exist in a nonverbal word recognition task.

Experiment 6

Method

Subjects. Seventeen graduate students and faculty members at the University of Texas at Austin participated voluntarily in the experiment. Eight were male and nine were female. Thirteen had participated in Experiment 1 or 2, and nine had also participated in Experiment 3, 4, or 5.

Stimuli. All of the stimulus items were concrete nouns. Half named living creatures (e.g., GOAT, BABY, BULL) and half named inanimate objects (e.g., RUBY, COAT, TENT). We chose the 30 items in each group without regard for initial letter.

Apparatus and procedure. The apparatus was the same as in the previous experiments, except that subjects responsed by pressing one of two buttons in a panel in front of them. The right button signified "animal" and the left button signified "nonanimal." The procedure was otherwise identical to that of Experiment 3. That is, all 60 items were presented in the I-O, O-I, and whole-word conditions.

Results

The average mean and median reaction times for the 17 subjects are listed in Table 6. For the mean data, the animal responses were faster than the nonanimal responses, $F(1, 16) = 24.10$, $p < .001$, and the main effect of condition was significant, $F(2, 32) = 19.36$, $p < .001$. In addition, the interaction of animal/nonanimal with condition was significant, $F(2, 32) = 4.54$, $p < .025$. The two orthogonal comparisons were significant: The two experimental conditions were reliably faster than the whole-word condition, $F(1, 16) = 26.62$, $p < .001$, and the O-I condition was faster than the I-O condition, $F(1, 16) = 6.77$, $p < .025$. This latter comparison also interacted with animal/nonanimal, $F(1, 16) = 10.06$, $p < .01$.

For the median data, the animal responses were again significantly faster than the nonanimal responses, $F(1, 16) = 32.68$, $p < .001$. In addition, the main effect of condition was significant, $F(2, 32) = 22.23$, $p < .001$, as were the two orthogonal comparisons: The two experimental conditions were reliably faster than the whole-word control condition, $F(1, 16) = 30.79$, $p < .001$, and the O-I condition was significantly faster than the I-O condition, $F(1, 16) = 8.76$, $p < .009$. None of the interactions was significant.

We performed a similar analysis on the number of errors made by each subject in each condition. The average numbers of errors made by each subject in each condition are listed in Table 7. A total of 123 errors were made (4% of the data). The analysis

Table 6
Averages of Mean and Median Naming Latencies (in msec) for Experiment 6

	Display condition		
Stimulus items	Whole word	Inside out	Outside in
	Mean		
Animal	557	545	520
Nonanimal	592	560	560
	Median		
Animal	536	518	497
Nonanimal	565	544	540

Table 7
Average Number of Errors per Subject in Experiment 6

	Display condition		
Stimulus items	Whole word	Inside out	Outside in
Animal	.88	1.65	1.12
Nonanimal	.76	1.65	1.18

revealed no significant difference between the number of errors made on animal trials and nonanimal trials, $F(1, 16) < 1$. However, there was a significant difference in the numbers of errors made in the three conditions, $F(2, 32) = 4.33$, $p < .03$. The orthogonal comparisons revealed that significantly more errors were made in the I-O condition than in the O-I condition, $F(1, 33) = 4.35$, $p < .05$, and that significantly more errors were made in the two letter-priming conditions than in the whole-word condition, $F(1, 33) = 8.57$, $p < .007$. Finally, none of the interactions in the error data was significant.

Discussion

Overall, the results of Experiment 6 are consistent with those of Experiments 3, 4, and 5. Again, priming with either the outside or the inside letters facilitated recognition (relative to the whole-word condition), as was shown in Experiment 3. Also, priming the outside letters led to overall faster recognition than did priming the inside letters. One exception to this pattern was the mean data for the nonanimal items, which showed no such difference despite a significant difference when the animal and nonanimal data were combined.

However, unlike the results of Experiments 3, 4, and 5, the results of Experiment 6 did manifest differences in error rates among the three conditions. For the experimental conditions, the condition with the longer latency, I-O, showed the larger error rate. This relationship does not appear to hold for the whole-word condition, since it exhibits longer latencies than the other two but a smaller error rate. However, this is probably an artifact of the fact that timing began with the onset of all the letters. Had overall response latencies been measured (i.e., timing from the onset of *any* letters to initiation of response), the whole-word condition would have become the shortest of the three. Thus, the error rates are positively correlated with overall response latency, so it is unlikely that any speed/accuracy tradeoff occurred.

General Discussion

This series of experiments was designed to provide an empirical test of one member of the currently popular family of parallel models of word recognition. Data on letter-naming latency in two letter-priming conditions in Experiments 1 and 2 enabled us to derive a prediction for word recognition latencies for the independent parallel model of word recognition. Specifically, the model predicts that word recognition should be facilitated equally by priming (by 50 msec) either the inside or the outside letters of a four-letter word. However, the results showed that priming the outside letters facilitated word processing more than did priming the inside letters. In the naming latency tasks, priming did not affect subjects' error rates, whereas in the experiment using an animal/nonanimal judgment, the conditions that produced longer overall latencies also produced higher error rates. Thus, Experiments 3–6 provide strong evidence against the independent parallel model. We found the same pattern of results with four different sets of materials and with two different experimental tasks, and the independent parallel model failed to predict it. In light of this evidence, it seems clear that the independent parallel model of word recognition should be rejected.

It should be pointed out, however, that in the particular independent parallel model that was tested, we assumed that all of the letters had to be apprehended before the word could be recognized. It remains unclear how robust the predictions would have been to violations of this assumption.

Nonetheless, it is worth considering exactly how the apparent failure of the independent parallel model bears on the myriad parallel models that are not independent. For instance, a parallel model in which the outside letters are processed independently but in which the processing of the inside letters is dependent on information about the outside letters would account nicely for the results of Experiments 3–6. Indeed, in most current parallel models, the letter-processing units are quite nonindependent, making use of some sort of facilitative effects of intraword context. Empirical support for such a notion is based on the reported perceptual advantage in tachistoscopic recognition enjoyed by letters in words over letters in isolation shown by Reicher (1969) and Wheeler (1970), which was discussed in the introduction. This facilitative interaction among the processors is typically believed to capitalize on the constraints of English orthography that help to restrict the alternatives at each letter position (Massaro, 1975) or to provide information about the proper position in the word of apprehended letters (Estes, 1975a, 1975b).

Nevertheless, the contribution of intraword context to letter recognition typically found in such experiments is not large. Johnston and McClelland (1973) compared subjects' ability to recognize letters in words with their ability to recognize letters embedded in noise characters (e.g., C in COIN vs. C in C###) in brief exposures. Here, the presence of the noise characters served to equate the two conditions for the effects of lateral interference, and the presence of the intraword context provided for about 14% better performance. However, there is recent evidence that shows that the size of the facilitative effect of intraword context decreases with increases in the quality of the visual stimulus.

In an elegant experiment, Massaro (1979) orthogonally manipulated the amount of visual information and the amount of contextual information in a letter recognition task. The subjects' task was to choose between the letters *e* and *c* in one session (and *h* and *n* in a second session) embedded in four-letter displays. The visual information was varied by changing the length of the horizontal bar that distinguishes *c* from *e* and by changing the length of the vertical bar that distinguishes *h* from *n*. Four types of contexts were used: that which supported the first letter of the pair and not the second, that which supported the second and not the first, that which supported both, and that which supported neither.

Massaro found that his data were fitted quite nicely by the equation

$$P(e) = (V_i)(C_j)/[(V_i)(C_j) + (1 - V_i)(D_j)], \quad (5)$$

based on Luce's (1959) choice axiom. In the equation, $P(e)$ is the probability that the subject will respond *e* (in the *e–c* series), V_i is an index of the extent to which the visual information supports *e*, C_j is an index of the extent to which the context supports *e*, and D_j is an index of the extent to which the context supports *c*. The quantities V_i, C_j, and D_j can vary between 0 and 1.

Now Equation 5 can be rewritten as

$$C_j = [P(e)](D_j)(1 - V_i)/(V_i)[1 - P(e)]. \quad (6)$$

From Equation 6 it can be seen that Massaro's model predicts that as the quality of the visual stimulus approaches perfection (i.e., as V_i approaches 1), the contribution of the context, C_j, goes to 0, without regard to the extent to which the context supports other letters, D_j. Thus, if we apply Massaro's model to the situation where the subject has abundant visual information, the model predicts that the subject needs to make no use of context and hence processes each letter independently. In the normal reading situation where the reader views high-contrast black letters on a white background in ample light for fixations of 200–250 msec, it is distinctly possible that readers make no use of intraword context at all.

Massaro's results support this notion. He found that the effects of contextual and visual information interacted such that when the visual information was least useful for choosing between the letter alternatives (i.e., at intermediate lengths of the critical bars), the effect of context was greatest. Conversely, when the visual information was most useful, the effect of context was least. Massaro also varied the interstimulus interval between the offset of the stimulus display and the onset of the postmask. Here, as the interstimulus interval was increased from 5 to 240 msec (and presumably the subjects were better able to make use of the visual information in their iconic store), the effect of context progressively diminished, especially for the *h–n* stimuli.

These results indicate that subjects are flexible enough to make use of whatever information is available to them that might allow them to perform their tasks. It may well prove to be the case that letter and word recognition theorists have been betrayed by the paradigm they have been using. That is, in situations where the number of errors made by a subject is the dependent measure, one must necessarily restrict the amount of visual information by using 30–50-msec exposures or by presenting words in the periphery. This procedure probably biases subjects in favor of using the extravisual information that is available to a far greater extent than it is used during ordinary reading. This in turn leads theorists to overestimate the contribution of intraword context in normal reading.

In conclusion, it has been argued that the dependent parallel models that employ intraword context become increasingly independent as the quality of the available visual information improves, and that for foveally fixated words in normal reading independence is likely to be the norm. Hence, evidence presented here against the independent parallel model might well prove to be evidence against the entire family of parallel models.

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Appendix

Table A1
Stimulus Materials Used in Experiment 1

AREA, REAR, EARS, ARSE	OSLO, SLOB, LOBO, OBOE
ARID, RIDE, IDES, DESK	PARE, AREA, REAR, EARS
ATOM, TOME, OMEN, MENT	RIDE, IDEA, DEAR, EARN
GRID, RIDE, IDEA, DEAR	SHOP, HOPE, OPEN, PENS
HEMI, EMIT, MITE, ITEM	SLAM, LAME, AMEN, MEND
HOME, OMEN, MEND, ENDS	SLAV, LAVE, AVER, VERY
ICED, CEDE, EDEN, DENT	SPAR, PARE, AREA, REAR
ICCN, CONE, ONES, NEST	TECH, ECHO, CHOP, HOPS
MACH, ACHE, CHEW, HEWN	THEM, HEMI, EMIT, MITE
MICE, ICED, CEDE, EDEN	TRAP, RAPE, APES, PEST
ORAL, RALE, ALES, LEST	

Table A2
Stimulus Materials Used in Experiment 4

ABED	EVIL	TAXI
AGOG	GAFF	TOGS
ALEE	GAVE	TONE
AMID	GIFT	TOUT
ARCH	IBIS	TOWN
AVOW	IDOL	TUCK
CHAT	INCH	TUNE
CHIT	ITCH	UGLY .
CHOW	ODDS	WAIT
COWL	OOZE	WEST
CROP	OVUM	WHIT
CURE	TAPS	WISE
EMIT		

Table A3
Stimulus Materials Used in Experiment 5

AIRY	KEPT	UNIT
ALSO	ONLY	URGE
ARCH	OPEN	USER
ARMS	SIGN	WAIL
CAME	STAG	WAIT
CARE	SWAP	WAVE
CULT	TAXI	WILL
EPIC	THIS	WILT
GATE	TILE	WITH
GENE	UGLY	

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