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ABSTRACT

Previous work shows that skilled college level readers tend to apprehend words as wholes, whereas they tend to process random strings of letters as a series of individual letters. Subjects in the study were forced to process words and non-word strings both serially and under conditions which allowed simultaneous processing, and their performances were compared. Five inter-connected studies were performed. Experiment one confirmed the parallel processing effect for words, showing a striking increase in the percentage of words correctly identified as the number of letters present on the screen at any one time increased. Experiment two showed that words could be processed in parallel with a fair degree of accuracy even when letters were displayed in random temporal order. Experiment three attempted to determine whether non-word strings bearing a statistical resemblance to English would show the parallel processing effect but found only weak positive evidence. Experiment four found no relation between the appearance of the effect and either the pronounceability or the frequency of non-word trigrams. Experiment five found no evidence that the effect extends beyond words to short phrases. (TO)

FINAL REPORT

Project No. 2-C-080

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THE USE OF MORPHOLOGICAL AND SYNTACTIC REGULARITIES IN WORD READING

August 1973

U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
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U. S. DEPARTMENT OF
HEALTH, EDUCATION AND WELFARE
Office of Education
National Center for Educational Research and Development

ABSTRACT

Previous work showed that skilled (college-level) readers use strikingly different strategies in processing words and random letter strings: words tend to be apprehended as wholes, "in parallel", whereas random strings tend to be processed as a series of individual letters. The general research strategy was to force subjects to process words and non-word strings serially, and then to compare their performance under such conditions with performance under conditions which allowed simultaneous processing. Forced serial processing was achieved by displaying stimulus strings one letter at a time on the screen of a computer-controlled oscilloscope and following each letter display with a "backward mask".

In the present research, five inter-connected studies were performed, all using this serial display technique, designed to confirm and extend the conclusions of the earlier work. Experiment I confirmed the "parallel processing effect" for words, showing a striking increase in the percentage of words correctly identified as the number of letters present on the screen at any one time increased (with per-letter display time constant). Experiment II showed that words could be processed in parallel with a fair degree of accuracy even when letters were displayed in random temporal order. Experiment III attempted to determine whether non-word strings bearing a statistical resemblance to English would show the parallel processing effect, but found only weak positive evidence. Experiment IV found no relation between the appearance of the effect and either the pronounceability or frequency of non-word trigrams. Experiment V found no evidence that the effect extends beyond words to short phrases.

I N T R O D U C T I O N

The experiments reported below are concerned with the same general problem: How does the skilled reader integrate the separate letters of a word into a single perceptual-cognitive whole? Clearly, learning to build whole words out of single letters is a crucial component in learning to read. If we understood more clearly the psychological mechanisms involved, we might better understand how to teach this essential skill.

The problem is a good deal more subtle and complex than may be immediately apparent to the lay reader. To recognize a word requires that we somehow take account of the information contained in individual letters, though we may not be conscious of individual letters at all in ordinary reading. Letter recognition is itself a complex process: even under constant conditions of illumination, visual orientation, etc., the image cast by a particular letter upon the retina varies widely, depending on typescript or handwriting, yet the brain extracts some essential continuity in all this variety. (See Neisser, 1967, Ch. 3 for a readable discussion of problems and theories in the area of pattern recognition.) At the same time, recognition of words is profoundly affected by the grammatical and semantic context in which these words appear, as well as by the "set" of the reader. Thus a fully adequate theory of word recognition must on the one hand explain how more "microscopic" pattern recognition processes are integrated into the larger process of word recognition, and on the other hand how the operation of the word recognition mechanism is conditioned by more "macroscopic" grammatical, semantic and motivational processes. It is remarkably difficult to answer even apparently simple questions about word recognition. For example, until recently there was little conclusive evidence on the issue of "serial vs. parallel processing", i.e. the question whether letters within words are processed by the brain one at a time, or all at once. Introspection, of course, argues that words are apprehended as wholes, not as sequences of letters. But introspections about rapid, semi-conscious processes can be misleading. In processing speech, for example, we also apprehend words as wholes; yet we know that a spoken word is an event that takes place over time. Clearly our brains have some specialized mechanisms of short term memory which preserve the initial parts of words as later parts come in. The time dimension is lost to our consciousness. Perhaps some similar unconscious mechanism is at work in word recognition. The question cannot be decided on introspective grounds; we require functional evidence of some sort. However, functional evidence has been hard to gather, precisely because word recognition is such a rapid, tightly integrated cognitive process.

In two recent papers (Travers, 1970; 1973) the author described a technique for studying the qeustion of parallel vs. serial processing. The technique in essence forces subjects to process letters in series. Performance under conditions of forced serial processing is then compared with performance under conditions which allow parallel processing. The technique and previous results are described here in some detail, since the present research builds upon both the method and earlier findings.

How can subjects be forced to process the letters within words serially? It might appear that this could be accomplished simply by displaying letters one at a time in rapid succession. However, if letters are printed from left to right across a screen at speeds which approximate those of ordinary reading, subjects are not forced to process them serially. Short-term visual storage ("iconic memory" in Neisser's terminology, 1967) preserves initial letters as later ones are displayed. Thus, despite serial display, several letters are available at once in iconic memory for parallel processing by higher cognitive mechanisms. It is assumed, following Neisser (1967), Sperling (1963, 1967) and many others that letters are "read out" of iconic memory by some higher mechanism, probably auditory or linguistic in nature. It is to this mechanism that the question of serial vs. parallel operation applies: does the subject read letters out of visual storage one at a time (and only build words at some later point in processing) or does he try to "chunk" letters into clusters which can be read all at once -- syllables, words, etc.?

Higher processing mechanisms can be forced to operate in series by adding to serial displays a "backward mask", which interferes with the retention of visual material in iconic memory. (See Figure 1 for clarification of the serial display technique with and without masking.) Backward masking refers to interference with the processing of a target stimulus caused by presentation of a later stimulus (the mask). The mechanisms of masking are complex, and depend upon a variety of stimulus parameters. (See Kahneman, 1968, and Turvey, 1973 for reviews and discussion.) However, the exact mechanism is not important for the present

UNMASKED

Time 50-200 msec.	Spatial Position					
1	M					
2		E				
3			T			
4				H		
5					O	
6						D
7						

MASKED

Time 50-200 msec.	Spatial Position					
1	M					
2	Ø	E				
3		Ø	T			
4			Ø	H		
5				Ø	O	
6					Ø	D
7						Ø

Figure 1. Serial Displays with and without Masking.

research, so long as one crucial assumption can be made: the presentation of the mask tends to decrease the reliability of visual memory for a particular letter; therefore, in order to retain that letter, the subject must turn to "higher", probably "auditory" strategies. Put more concretely, he will probably try to name individual letters to himself rather than waiting until all letters are present in visual storage and then naming the word.

The guiding hypothesis of almost all the research to be discussed in this report is that individual letter processing is an inefficient and unnatural strategy for the skilled reader; he prefers to process groups of letters, whole words, or even longer phrases, simultaneously. Thus words displayed one letter at a time with masking should be hard for him to identify. In contrast, serial display without masking, which allows him to make use of iconic memory and to process letters in parallel, should be much easier to deal with.

The results of a first test of this hypothesis (Travers, 1970; 1973) are shown in Figure 2, where the percentage of words correctly identified (by 20 college-student subjects) is given as a function of letter exposure duration and of masking condition. The results are clear-cut: at brief exposure durations (50 and 100 milliseconds per letter) the presence of the mask impairs recognition significantly ($p < .01$ by studentized range test following a significant F-test. See Winer, 1962, pp.77-85 for a description of the test). At longer exposures, the mask does not matter. The longest exposure durations were sufficient

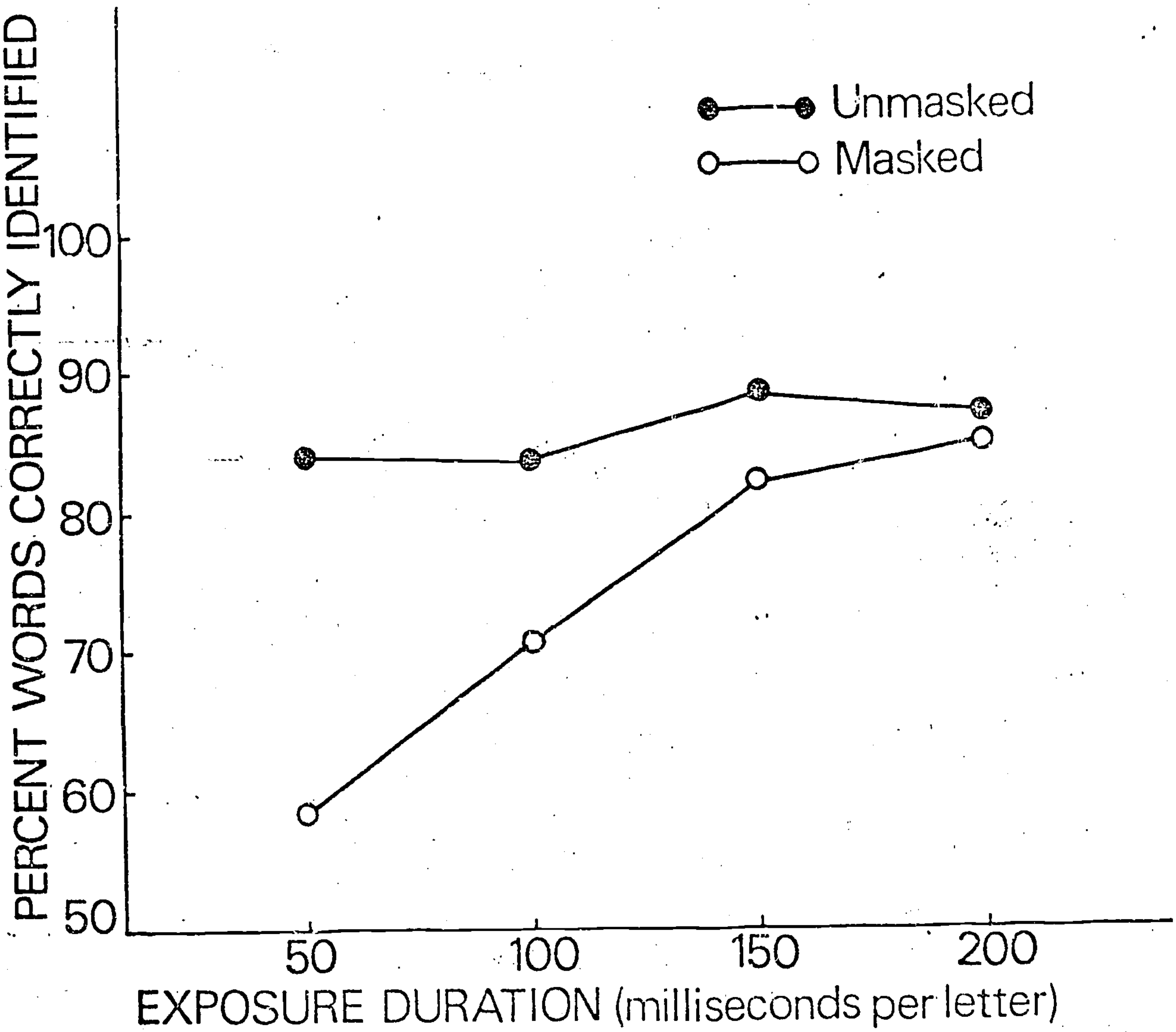

Figure 2. Word Recognition under Conditions of Masked and Unmasked Serial Display.

to allow subjects time to recognize and name individual letters covertly (see Landauer, 1962, and Pierce and Karlin, 1957, for estimates of the time required for subvocal naming.) However, such a processing rate is far slower than the rate of ordinary reading. At briefer exposure durations, which begin to approach the rate of reading (a processing rate of 50 msec. per letter corresponds to a reading rate of about 240-300 words per minute) the mask has a marked effect. Thus, visual conditions which tend to force serial processing impair reading at display speeds which approach the speed of normal reading.

This finding is open to an alternative explanation, however: the mask did not merely prevent clusters of letters from being present simultaneously in iconic memory. It curtailed the duration of individual letters in iconic memory as well. Thus the impairment in word recognition associated with masking might be due not to forced serial processing but to the fact that the mask reduced the time available to process letters individually. Also, the finding raised an important new question: was the masking effect due entirely to basic properties of the visual system, or did it depend on the subjects' knowledge of the structural properties of the stimulus strings? These issues were treated in a second study, in which the visual conditions of the first study were duplicated, but the stimuli were random strings of letters rather than words.

The results, shown in Figure 3, were again clearcut. This mask made no difference, at any exposure duration, in the identification of random letter strings or of individual letters within such strings.

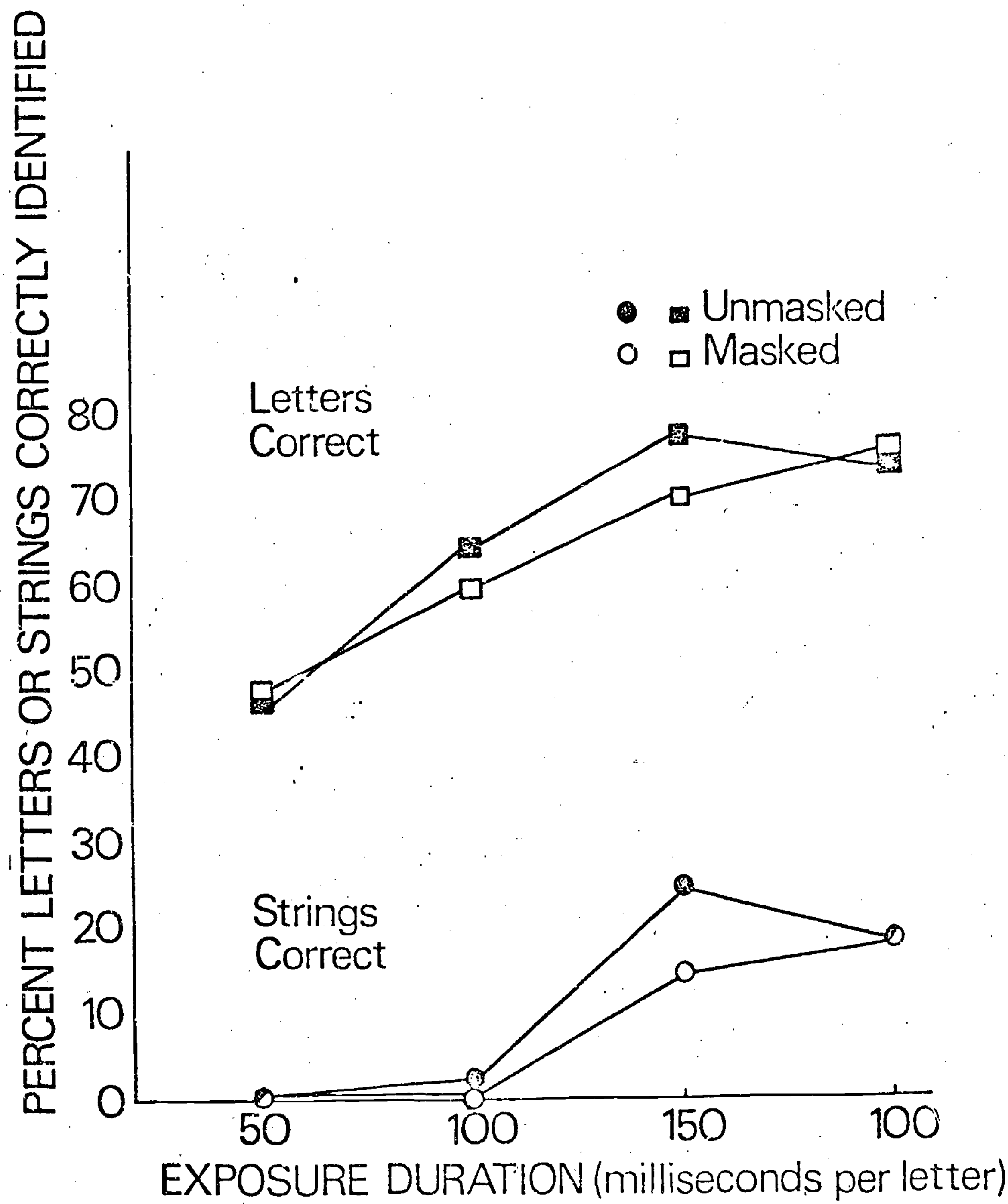

Figure 3. Recognition of Random Letter Strings under Conditions of Masked and Unmasked Serial Display.

The conclusions to be drawn are two: (1) the effects of the mask on word-recognition are not due to interference with recognition of individual ~~strings~~ letters. (2) The effects of the mask depend on the type of stimulus letter string employed. Summarized briefly, the two experiments show that skilled readers tend to process words or sections of words in parallel, whereas they process random letter strings in series or in smaller sections. (See Travers, 1970; 1973 for additional data and a more complete statement of the argument.)

The pattern of results obtained for words -- marked effects of masking at rapid exposure durations, small or zero effects at durations long enough to permit naming of letters -- will be called the "masking effect" or "parallel processing effect" throughout this paper. The present research deals with a series of further questions raised by the studies just described.

A. First, one critic of those studies (Phillip Liss, personal communication) pointed out that unmasked serial displays may not allow full parallel processing of words. One commonly accepted estimate of the duration of iconic memory is about 250 msec. (Haber and Standing, 1969.) By this estimate initial letters would be lost to iconic memory whenever words over five letters in length were displayed serially, even at rates as fast as 50 msec. per letter. While this argument is probably correct, the real issue is whether enough letters are retained in iconic memory to allow higher processing mechanisms to operate at peak efficiency. Liss felt that incomplete parallel processing might account for the fact that ceiling performance in the unmasked condition with word stimuli was only about 86%. On the other hand, this less than perfect accuracy might be due to some other factor, such as subject fatigue. (Subjects identified a total of 550 words in this experiment.) Liss proposed that a new condition be run to settle this question: subjects should be shown words under ordinary, non-serial display conditions, i.e. with all letters present simultaneously in normal positions. If this condition produced more nearly perfect performance, it could be concluded that serial display *per se* did interfere significantly with parallel processing, at least within certain time limits.

In the present series, two experiments were run which bore on Liss' conjecture that the failure of unmasked serial display to allow full parallel processing may have transfered subject performance in the unmasked conditions of the earlier experiments. These new experiments were also designed to strengthen and extend the conclusions of two previous studies concerning the importance of parallel processing in word recognition, and the utility of the serial-display-with-masking technique as a means for studying word recognition.

(1) Words were displayed with and without masks. Letters within words were shown with varying degrees of temporal overlap. That is, some words were shown one letter at a time, some two letters at a time, etc. At the upper extreme, the words were displayed as wholes, the condition Liss had suggested. (See Figure 4, page 22, for further clarification of the display conditions.) The "masked" conditions of the

experiment were designed to show whether increasing temporal overlap, interpreted as increased opportunity for parallel processing, would improve performance, as the theory underlying the earlier experiments suggested. The "unmasked" conditions were designed to determine whether an increase in the number of letters simultaneously present on the screen would affect subjects' performance in the absence of a mask. As argued above, an improvement in accuracy with increasing overlap under non-masked conditions would support Liss' claim that absence of the mask is insufficient to allow full parallel processing. However, if accuracy proved to be independent of degree of overlap, we could conclude that iconic memory allows subjects to retain as many letters as can be used effectively by higher processing mechanisms, even if retention is less than complete.

(2) Subjects were shown words, one letter at a time, with and without a mask. Some words were shown with letters in normal position and in temporal order corresponding to their left-right spatial sequence. Other words were shown with letters in position but in random temporal order (see Figure 6, page 32, for further clarification of the display conditions).

The unmasked conditions of this study may be seen as a rather demanding test of the hypothesis that iconic memory preserves temporally prior letters as other letters are being shown. If words can be read with a high degree of accuracy even when their separate letters are displayed in random order (but in proper spatial position) surely some short term memory mechanism must be operating to preserve and reorder those letters. The masked conditions serve as a check on the possibility that subjects first identify individual letters in scrambled order and then unscramble them after the display is gone. When the mask is present, interfering with iconic memory, this conscious anagram strategy is the only one available. When the mask is absent, the alternative of retaining the letters visually and identifying them as a body is also available. A comparison of recognition levels in the two conditions thus is another way of gauging the role of iconic memory.

The masked conditions of this study also serve as a further test of the hypothesis that masking forces serial processing. We would expect serial processing to be much more effective when letters are presented in proper order than when they are not. When the temporal order of letters corresponds to their spatial arrangement, they spell a word uniquely; when the temporal order conflicts with the spatial arrangement, the subject may be confused by the fact that several words can be formed from the same set of letters (e.g. SPOT, STOP, POTS, TOPS, OPTS, POST). Also, when letters are in order, previously processed letters can help the subject guess at the next one to come; when they are out of order this is much more difficult. Though the clever subject may be able to offset these difficulties by quick solution of anagrams, he must still be at a disadvantage relative to his own performance on masked displays in normal order.

B. Second, the completed experiments reported above showed clearly that words are processed differently from random strings. However, words differ from random strings in many ways: they are familiar to the subjects as total patterns; they obey structural rules of various kinds; they relate to the sound patterns of the language; they have meanings, etc.; which of these aspects of words is or are responsible for subjects' ability to process words in parallel? As a first approach to the problem, the following experiment was conducted: non-word strings bearing a definite statistical relationship to the structure of English were constructed. The strings represented different "orders of approximation" to English, as described by Shannon (1948). Increasing statistical resemblance to English is known to facilitate identification of non-word strings. (Miller, Bruner and Postman, 1954.) Strings were then shown to subjects under conditions of serial display, with and without masking. The point of the experiment was to discover whether increasing statistical resemblance to English produced performance that was more and more "wordlike": would non-word strings which obeyed English structural rules to some degree show a parallel processing (masking) effect? And would this effect increase as statistical resemblance to English increased?

To pursue further the issues raised in the preceding paragraph, an additional small-scale pilot study was conducted in which an attempt was made to compare the effects of pronouncability of strings against their sheer statistical resemblance to English. The aim was to refine further our understanding of the mechanism underlying the parallel processing effect.

This line of investigation was suggested by the work of Eleanor Gibson and her colleagues (Gibson, Pick, Osser and Hammond, 1962). Gibson, <u>et al</u> showed that pronouncable nonsense syllables (e.g. GLURCK) were more easily recognized in tachistoscopic displays than unpronouncable rearrangements of the same letters (e.g. CKURGL); the authors argued that "graphema-phoneme correspondence" affected the ease with which letter strings can be identified. Anisfeld (1964) suggested that letter combinations in Gibson's pronouncable strings were more common in printed English than letter clusters in her unprouncable strings. Gibson (1964) replied that summed diagram frequencies did not differ between pronouncable and unpronouncable strings; therefore pronouncability appeared to exert its effects independently of letter-cluster frequencies. However, Olivier (personal communication) has argued that summed diagram frequencies are not a meaningful measure of the Englishness" of a letter string. Olivier devised a measure of Englishness based on Markov principles (described in a later section) and showed that it correlated highly with pronouncability for Gibson's strings. In addition, Gibson replicated her study with totally, congenitally deaf subjects who could not possibly have heard the various letter clusters pronounced (Gibson, Shurcliff and Yonas, 1970). Therefore, on both theoretical and empirical grounds the effects of pronouncability appeared to be suspect.

On the other hand, statistical frequency of letter clusters has also been called into question as a variable controlling tachistoscopic recognition. Postman and Conger (1954) found no correlation between the frequency of occurence of trigrams in English and their recognizability in tachistoscopic displays. A possible explanation for their null results is the fact that many common trigrams are difficult to encode and pronounce (e.g. CTI).

In the present research, trigrams embodying the four possible combinations of high and low frequency, high and low pronounceability, were shown under conditions of serial display, with and without masking. The basic experimental question was whether the masking effect (i.e. the parallel processing effect) would be obtained for strings of high frequency, high pronounceability, or both, or neither.

C. Third, while the completed experiments dealt exclusively with words as units of perceptual-cognitive analysis, it is often argued that skilled readers can apprehend at a glance larger linguistic units, such as phrases, clauses or even sentences. (See, for example, the provocative study of Bever and Bower, 1966.) Therefore it seemed worthwhile to performa a straightforward extension of the word studies, using short, common phrases as stimuli (e.g. "the blue sky"). Phrases were displayed one letter at a time (spaces were treated as letters) with letters in normal position and temporal order. Two exposure durations were used, one (200 msec.) long enough to allow covert letter-naming, one (50 msec.) too brief for this strategy to work. Half the displays incorporated a mask following each letter; half did not. The experimental question was simply whether the masking or parallel processing effect obtained for words would be obtained for phrases as well. This study was also conducted on a small-scale, pilot basis.

In summary, five experiments were performed. For convenience in reference throughout the rest of this report, they will be numbered and labeled as follows:

I. Temporal Overlap Study

II. Temporal Order Variation Study

III. Orders of Approximation Study

IV. Structure-Pronouncability Pilot

V. Phrase Pilot

In addition, a sixth study was completed on one of the mechanisms presumed to underly all of the other studies, namely non-visual processing of stimuli following a mask. Because of a technical error discovered in the process of writing this report, the sixth study failed to yield useful data. The study is discussed briefly in Appendix G.

The "Method" section of this report describes general features of the apparatus and procedure common to all five studies. In the interest of clarity and continuity, specific methods unique to particular studies are presented along with the results of those studies in the third section of the report, which thus consists of five subdivisions, one for each experiment.

GENERAL METHODS

Apparatus

All of the experiments to be reported were performed at the Computer-Based Laboratory of the Harvard University Psychology Department. Words and letter strings were displayed on the cathode-ray tube (CRT) of an oscilloscope controlled by a Digital Equipment Corporation PDP-4 computer. Display programming was facilitated by use of "Lexigraph", a language devised for experiments of this type by ~~David~~ Daniel Forsyth. Two oscilloscopes were used in the various studies -- a Digital Equipment Corporation Type 340-Precision Display in Experiments I and IV, and a Fairchild Type 737-A Large Screen Indicator in Experiments II, III and IV.

In both cases the CRTs were equipped with P24 phosphors, which fade to 1/10 of peak intensity in 1.5 <u>micro</u>seconds. The time required for a letter to reach peak intensity was about 900 microseconds, including both the time needed by the computer to process a display instruction and the time for the phosphors to respond. Thus the apparatus provided close control over stimulus duration; the total startup and fade time of less than a millisecond is negligible when compared to the briefest stimulus duration used in any of the present studies (48 msec.).

Lexigraph uses upper-case block characters formed by a pattern of closely spaced dots. At the letter sizes and exposure durations used in the present experiments, the dots were barely perceptible; characters essentially appeared to be formed by unbroken lines. Characters in Experiments I, II, III and IV measured approximately 5/32" by 7/32". In Experiment IV characters measured 5/64" by 7/64".

The visual angle subtended by the characters varied, since subjects were allowed to adjust their viewing distance for comfort. Typical viewing distances were about 18 to 24 inches. Characters appeared in luminescent green against a dark gray background.

Masking stimuli were a cross-hatched number symbol (#) and a zero crossed with a diagonal (Ø). These were the most letter-like symbols available in Lexigraph which were not themselves letters or digits. Both patterns were similar in size and brightness to letters. The number symbol was used in Experiment III and the zero in Experiments I, II, IV and V.

Procedure

Instructions to subjects were displayed on the CRT face. A research assistant (Robert Shriver) was present at the beginning of the procedure to answer questions but then left subjects alone. Subjects recorded their word and letter-string identifications in writing. (The recording pad was illuminated by a dim light. Otherwise the experimental room was dark, and the face of the CRT was shielded from the light.) In all experiments subjects controlled the onset of stimuli by a button connected to the computer. They were instructed to proceed at a comfortable pace and to rest whenever necessary. After the subject pressed the button, a pair of colons (: :) appeared for several hundred msec, bracketing the space in which the word or letter string was to appear.

The colons served three purposes: (1) signalling the onset of the stimulus; (2) showing the subject where to focus his eyes; (3) giving the subject some idea how long the stimulus word or letter string would be. Subjects were given a small number of practice trials, usually about ten, to familiarize them in advance with each condition of every experiment.

Subjects

Subjects in all studies were college undergraduates or graduates, mostly from Harvard and Radcliffe. None reported specific reading disabilities. One reported a minor vision defect, but his performance was similar to that of others in the study in which he took part (Experiment II).

Word Lists

Stimulus lists for all experiments involving words were drawn from the Kučera and Francis (1967) count of one million words of printed English. All words used were common, with frequenies of occurrence falling between 25 and 300 in the million-word sample. This frequency range guaranteed that all words would be familiar to the subject population, but it excluded words of extremely high frequency which might introduce distortions into the subjects' performance and make it difficult to balance frequencies across experimental conditions.

In every case where word identification levels were compared across different visual conditions, the word lists used in the different conditions had highly similar frequency distributions, with means not more than a few percentage points apart. An important element in the control on word frequency was the use of a procedure for equalizing word frequencies across word lengths. (See Travers, 1970, for a description of the control procedure.) Short words are generally more common than long ones, but in all of the present experiments, words of different lengths had approximately the same average frequencies. Different studies employed words varying in length from three to eight letters.

SPECIFIC METHODS AND RESULTS

Experiment I: Temporal Overlap Study

A. Method

As outlined in the introduction, the temporal overlap study was designed as a further test of the hypothesis that words are processed in parallel, and as a check on a critic's claim that serial display without masking does not permit full parallel processing.

Common English words were displayed in four formats (see Figure 4A for additional clarification):

(1) Zero-overlap, or serial presentation -- words were printed across the CRT face one letter at a time, with letters in normal relative positions and in temporal order corresponding to normal left-right spatial sequence.

(2) Diagram-overlap -- words were printed left-to-right as in the first condition, but as a series of diagrams rather than single letters. The time span for each letter overlapped 50% with the preceding letter and 50% with the following letter.

(3) Trigram-overlap -- words were printed left-to-right as a series of trigrams. Each letter overlapped 67% in time with the immediately preceding and following letters, and 33% in time with letters removed by one letter-position to the left or right.

(4) Simultaneous or whole-word display -- ~~whole-word~~ words were shown with all letters present on the screen at once, in normal adjacent spatial

UNMASKED DISPLAYS

Zero-Overlap (Serial Display) — spatial position — 48 msec.

Time	1	2	3	4	5	6
1	M					
2		E				
3			T			
4				H		
5					O	
6						D

Digram Overlap — 24 msec.

Time	1	2	3	4	5	6
1	M					
2	M	E				
3		E	T			
4			T	H		
5				H	O	
6					O	D
7						D

Trigram Overlap — 16 msec.

Time	1	2	3	4	5	6
1	M					
2	M	E				
3	M	E	T			
4		E	T	H		
5			T	H	O	
6				H	O	D
7					O	D
8						D

Whole Word Displa[y] — 48 msec.

Time	1	2	3	4	5	6
1	M	E	T	H	O	D

MASKED DISPLAYS

Zero-Overlap (Serial Display) — 48 msec.

Time	1	2	3	4	5	6
1	M					
2	Ø	E				
3		Ø	T			
4			Ø	H		
5				Ø	O	
6					Ø	D
7						Ø

Digram Overlap — 24 msec.

Time	1	2	3	4	5	6
1	M					
2	M	E				
3	Ø	E	T			
4	Ø	Ø	T	H		
5		Ø	Ø	H	O	
6			Ø	Ø	O	D
7				Ø	Ø	D
8					Ø	Ø
9						Ø

Trigram Overlap — 16 msec.

Time	1	2	3	4	5	6
1	M					
2	M	E				
3	M	E	T			
4	Ø	E	T	H		
5	Ø	Ø	T	H	O	
6	Ø	Ø	Ø	H	O	D
7		Ø	Ø	Ø	O	D
8			Ø	Ø	Ø	D
9				Ø	Ø	Ø
10					Ø	Ø
11						Ø

Whole Word Displa[y] — 48 msec.

Time	1	2	3	4	5	6
1	M	E	T	H	O	D
2	Ø	Ø	Ø	Ø	Ø	Ø

Figure 4. Display Conditions for Experiment I -- Temporal Overlap Study.

positions. The four types of display thus represent increasing degrees of temporal and spatial overlap among letters within words.

Within each overlap condition, half the words had a "zero" mask following each letter or letter-cluster, and half had no mask. Under the assumption that masking forces the subject to process the masked blocks of material in sequence, the four masked conditions should allow increasing amounts of parallel processing, from none at all (in the serial display condition) to complete parallel processing (in the simultaneous display conditions).

The display time for each letter was kept constant at 48 msec. Therefore, increasing temporal overlap entailed a decrease in total processing time for the word. For example, a five-letter word displayed one letter at a time consumed a total of 240 msec. A five-letter word displayed with diagram overlap required 144 msec, with trigram overlap 102 msec, and with simultaneous display of all letters, 48 msec. Increased opportunity for parallel processing was invariably associated with less total processing time. If subjects' word-recognition performance improved with increasing overlap in the masked conditions, this fact would represent rather strong evidence for the utility of parallel processing.

By hypothesis the unmasked conditions all allow parallel processing, since whole words can be preserved in iconic memory even when their letters are displayed serially. If this hypothesis is correct, word-recognition in all the unmasked conditions should be highly accurate. Moreover, increasing the number of letters present on the screen at one time should have little effect on recognition accuracy. However, if the critic who raised a question about the degree of parallel processing possible under conditions of unmasked serial display were correct, such a pattern might not be obtained. In particular, the simultaneous or whole-word display condition might produce better recognition than other conditions, since it is the only one which allows full parallel processing.

Ten subjects took part in the experiment. Each subject identified a total of 200 words, 25 in each of the eight experimental conditions (four degrees of overlap, each with and without masking). Each block of 25 words included five words of each length from four to eight letters. Words of different length were presented in random order within conditions. Conditions were presented as blocks, and the order of the blocks was randomized across subjects. (See Appendix A for a complete list of stimulus words for Experiment I, with their frequencies in printed English.)

B. Results

The results of the temporal overlap experiment are presented graphically in Figure 5. The same data, with an additional breakdown by word length, are given in Table 1.

The data from the masked conditions give strong support to the hypothesis that letters within words are habitually processed in parallel by skilled readers. When a mask is present, controlling the

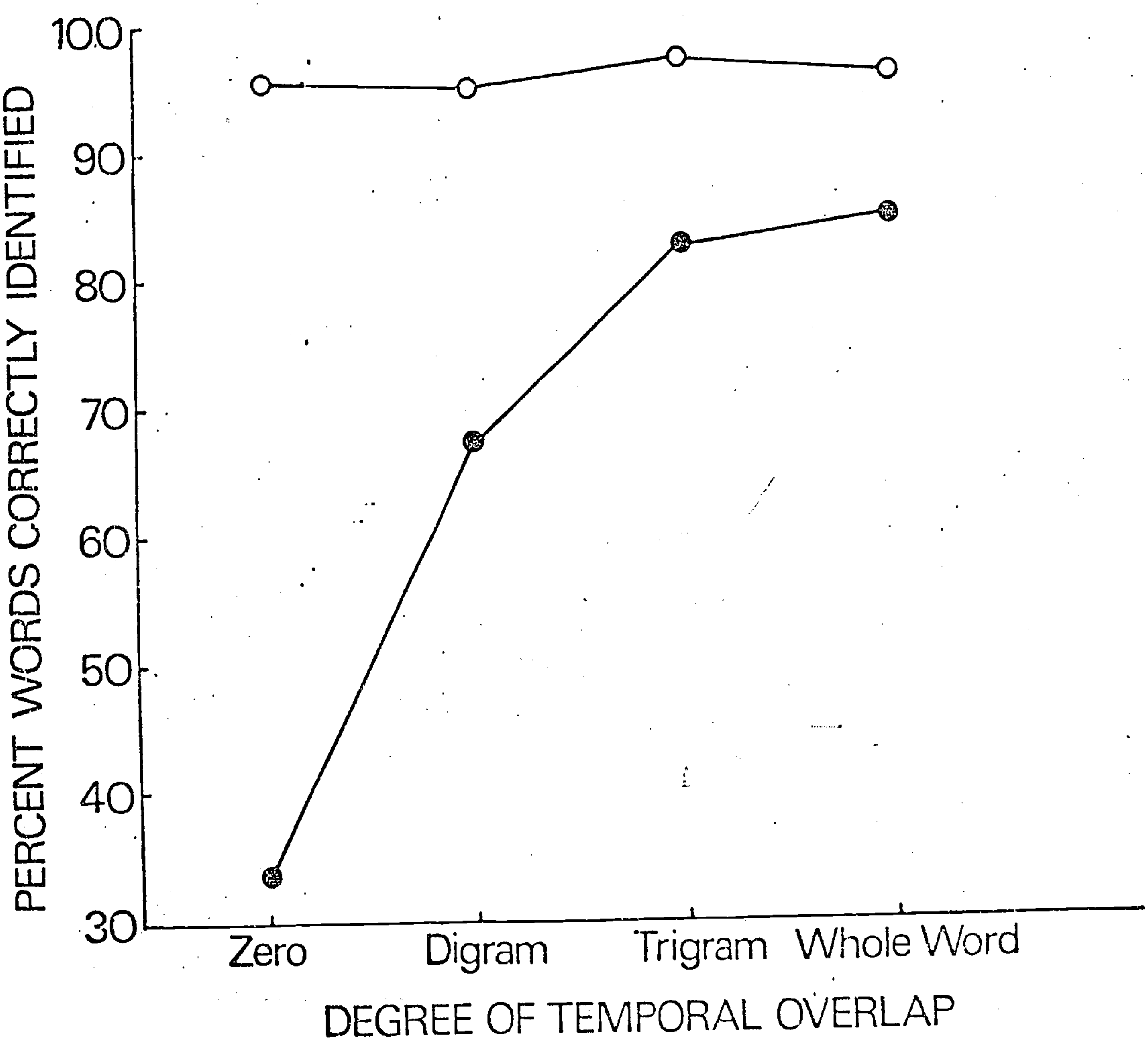

Figure 5. Results of Temporal Overlap Study: Percentage of Words Correctly Identified as a Function of Masking Condition and Degree of Overlap

TABLE 1

Experiment I: Temporal Overlap Study

Number and Percent of Words Correctly Identified as a Function of Word Length, Degree of Overlap and Masking Condition.

A. Unmasked — Degree of Overlap

Word Length (Letters)	1. Serial Display		2. Digram Overlap		3. Trigram Overlap		4. Simultaneous Display		TOTAL
4	48	(96%)	50	(100%)	48	(96%)	48	(96%)	194(97.0%)
5	49	(98%)	48	(96%)	48	(96%)	49	(98%)	194(97.0%)
6	49	(98%)	50	(100%)	47	(94%)	50	(100%)	196(98.0%)
7	48	(96%)	47	(94%)	49	(98%)	49	(98%)	193(96.5%)
8	44	(88%)	42	(84%)	50	(100%)	46	(92%)	182(91.0%)
TOTAL	238	(95.2%)	237	(94.8%)	242	(96.8%)	242	(96.8%)	959(95.9%)

B. Masked — Degree of Overlap

Word Length (Letters)	1. Serial Display		2. Digram Overlap		3. Trigram Overlap		4. Simultaneous Display		TOTAL
4	20	(40%)	30	(60%)	40	(80%)	43	(86%)	133(66.5%)
5	18	(36%)	32	(64%)	42	(84%)	44	(88%)	136(68.0%)
6	14	(23%)*	40	(80%)	49	(98%)	43	(86%)	146(73.0%)
7	22	(44%)	32	(64%)	41	(82%)	41	(82%)	136(68.0%)
8	13	(26%)	34	(68%)	34	(68%)	40	(80%)	121(60.5%)
TOTAL	87	(33.5%)*	168	(67.2%)	206	(82.4%)	211	(84.4%)	672(66.5%)

*Due to an error in experimental procedure, subjects saw 6 items in the masked, serial six-letter condition.

span of letters which can be processed at any one time, the outcome is a monotonic increase in the accuracy of word identification as that span increased. Only 33.5% of words displayed one letter at a time were recognized. In contrast, 84.4% of words displayed as wholes were identified. The diagram and trigram overlap conditions produced intermediate results -- 67.2% and 82.4% respectively. The serial display, or single-letter, condition was significantly different from the other three. (For the serial-diagram comparison, $t=4.0$, $p<.001$; for the serial-trigram comparison, $t=7.6$, $p<.001$: for the serial-simultaneous comparison, $t=7.1$, $p<.001$.) In addition, the diagram overlap condition was significantly different from the trigram condition ($t=4.5$, $p<.001$) and from the simultaneous condition ($t=4.3$, $p<.001$). The trigram-whole word comparison was non-significant. In sum, when the mask is present, the larger the group of letters available at any one time, the more easily words are identified, even though increases in the letter span are associated with a marked decrease in processing time for the word as a whole. The effect is strong up to clusters of three letters and negligible thereafter.

The data from the unmasked conditions show near-perfect performance regardless of the degree of overlap. (Identification levels vary from 94.8% to 96.8% across overlap conditions.) Needless to say, none of these differences is statistically significant. The high level of performance in the unmasked conditions and the lack of association between overlap and performance strongly suggests that serial display without masking does permit a substantial amount of parallel processing. Particularly striking is the fact that words displayed as wholes are recognized no better than words presented one letter at a time.

It is possible that, even without a mask, increasing temporal overlap does permit increased parallel processing, but that this effect is offset by the decrease in total processing time as overlap increases. Even if this conjecture is correct, however, it cannot account for the steep rise in accuracy observed with increasing overlap in the masked conditions. Clearly, the unmasked conditions allow a great deal more parallel processing than the masked ones. The fact that (in the masked condition) trigram overlap produces accuracy levels comparable to those produced by whole-word displays also suggests that subjects may not need to process whole words in parallel; the recognition system seems to hit peak efficiency as long as three-letter clusters are available for simultaneous analysis.

The fact that performance in the unmasked conditions in the present study was substantially closer to perfect than had been the case in earlier studies (about 96% as opposed to 86%) suggests that subject fatigue, or some factor, other than incomplete parallel processing, was responsible for the low ceiling in the earlier work. It may also be noted that performance in the masked serial condition was substantially worse in the present study than in the earlier experiment (33% versus 58% correct). This may be due to greater effectiveness of the "zero" mask than the crosshatch, which was used in the previous study; it may be due to less experience on the part of the subject with the display (25 versus 100 trials); or, of course, it may be due to some other uncontrolled factor. It cannot, however, be due to general differences in the equipment or subject populations, since in the unmasked condition performance was better in this experiment than in the previous one.

* * * * *

Experiment II: Temporal Order Variation Study

A. Method

As outlined earlier, the order variations study was designed partly as a stringent test of the hypothesis that unmasked serial display allows retention of letters in iconic memory. It was also designed to further confirm and extend the propositions that (a) masked serial displays force serial readout of letters from iconic memory, and (b) skilled readers habitually process words in parallel.

Words were displayed one letter at a time at exposure durations of 50 milliseconds per letter. All of the words used in the study were short -- three to five letters. This restriction was adopted for the following reason: serial displays tend to provoke eye movements. When the displays sweep left-to-right in conventional temporal order, eye movements tend to follow in the right direction. When displays hop randomly from letter-position to letter-position, however, the eye movements provoked by the first few letters are unlikely to guide the eyes to an optimal point of focus for later letters. If a subject moved his eyes during a randomly-ordered display he might easily miss some of the later letters. There would be no way to guarantee that all letters registered in iconic memory or to equate the effects of eye movements between random and conventionally-ordered displays. However, the latency for an eye movement is just under 200 milliseconds (Woodworth and Schlosberg, 1954, p.502). Therefore, by keeping the total display time for a word under 200 msec. it was possible to prevent the subject from making eye movements during the display. At exposure durations of 50 msec. per letter, this required restriction of the length of words to four letters or less. (The five-letter words were included as a check on the above reasoning; a decline in performance as word lengths increase from four to five letters would tend to support the argument just stated.) It was not desirable to lower the 50 msec. letter exposure duration because Mayzner and his associates (e.g. Mayzner, Tresselt and Cohen, 1966; Mayzner and Tresselt, 1970) have shown that serial displays at faster rates produce a curious perceptual effect ("sequential blanking") in which certain letters simply disappear subjectively.

Subjects identified a total of 288 words in this experiment, 72 with masks and 216 without. One-third of the words in each condition (24 and 72 words respectively) were three letters long, one-third four letters long, one-third five letters long. Words were displayed one letter at a time, with letters in proper spatial position. The temporal order in which letters were presented was determined as follows: in the case of three and four-letter words, all possible orderings were used. Each of the six possible orderings of three-letter words appeared four times in the block of masked displays and twelve times in the unmasked displays. Each of the 24 possible orderings of four letter words appeared once in the masked displays and three times in the unmasked displays. The presentation order of the different temporal arrangements was random. In the case of the five-letter words, which have 120 possible orderings, a random selection procedure was used to determine the orderings in both the masked and unmasked conditions. The complete list of stimulus words used in this experiment, with their frequencies in printed English, is given in Appendix B. Ten subjects were run in this study. The display conditions are further clarified in Figure 6.

The procedures for selecting temporal orders of presentation guranteed, at least in the case of three and four-letter words, that a subset of the words would be displayed in normal temporal order, i.e. an order corresponding to the left-right spatial arrangement of letters. Sixteen three-letter words (12 unmasked, 4 masked) and four four-letter words (3 unmasked, 1 masked) were shown in "normal" order. In addition, random selection dictated that two five-letter words in the unmasked condition also be shown in "normal" order. Thus the experiment incorporated an internal comparison of the effects of "random" versus "normal" ordering, as well as providing data that could be compared

NORMAL ORDER

UNMASKED

Spatial Position

Time 50 msec.	1	2	3	4	5	6
1	M					
2		E				
3			T			
4				H		
5					O	
6						D

MASKED

Spatial Position

Time 50 msec.	1	2	3	4	5	6
1	M					
2	Ø	E				
3		Ø	T			
4			Ø	H		
5				Ø	O	
6					Ø	D
7						Ø

RANDOM ORDER

UNMASKED

Spatial Position

Time 50 msec.	1	2	3	4	5	6
1		E				
2						D
3				H		
4			T			
5	M					
6					O	

MASKED

Spatial Position

Time 50 msec.	1	2	3	4	5	6
1				H		
2				Ø	O	
3	M				Ø	
4	Ø					D
5			T			Ø
6		E	Ø			
7		Ø				

Figure 6. Display Conditions for Experiment II -- Temporal Order Variation Study.

with other studies in which strictly normal ordering was used.

B. Results

The results of the temporal order variation study are shown in Table 2, where the number and percentage of words identified correctly are shown as a function of masking condition, normal versus random temporal order, and word length. The data suggest several conclusions:

(1) In the absence of a mask, words can be identified with a relatively high degree of accuracy (76.1%) even when displayed with letters in random order. Subjects are able to preserve and reorder letters through use of some form of short-term storage and/or through "unscrambling" words after the display is gone.

(2) When a mask is present, only 20.7% of randomly ordered words are identified. It is known from earlier work (Travers, 1970, 1973) that masking interferes relatively little with individual letter identification at the exposure durations used in this study. Moreover, it can be assumed that the subject's ability to unscramble words is the same across masking conditions, given equal accuracy in identifying individual letters. Therefore it can be concluded that the large difference between the masked and unmasked conditions (55.4%) is due to the operation of iconic memory, or some other form of storage and ordering mechanism, rather than to a conscious process of anagram solution after the display. It should be mentioned, however, that subjects vary widely in terms of reported strategies for dealing with displays of this type.

TABLE 2

Experiment II: Temporal Order Variation Study

Number and Percent of Words Correctly Identified as a Function of Word Length, Masking Condition and Presentation Order of Letters.

MASKED

	Normal Order	Random Order	TOTAL
3-letter	18 (45.0%)	71(35.5%)	89(37.1%)
4-letter	1 (10%)	48(20.9%)	49(20.4%)
5-letter	—	20 (8.3%)	20 (8.3%)
TOTAL	19 (38.0%)	139(20.7%)	158(21.9%)

UNMASKED

	Normal Order	Random Order	TOTAL	TOTAL
3-letter	113(94.2%)	486(81.0%)	599(83.2%)	688(71.7%)
4-letter	29(96.7%)	553(80.1%)	582(80.8%)	631(65.7%)
5-letter	20(100%)	477(68.1%)	497(69.0%)	517(53.9%)
TOTAL	162(95.3%)	1516(76.1%)	1678(77.7%)	1836(63.8%)

While none report an experience of visual simultaneity of letters, several report use of a "visual" strategy for identifying words -- "taking in" the entire display and identifying the words as wholes. Others report an attempt to identify individual letters and unscramble their order.

(3) When unmasked words are presented in "normal" order, levels of identification are very high, comparable to the levels obtained for similar displays in Experiment I (95.3% overall). The 17.6% difference between "normal" and "random" unmasked displays is statistically significant ($t = 7.02$ $p > .001$). The difference indicates that iconic memory (or whatever form of storage and ordering mechanism operates in this study) cannot preserve entire words. Thus Philip Liss appears to be correct in his assertion that some information is lost by iconic memory under serial display conditions, even without masking.

(4) When masked words are presented in normal order, levels of identification are again similar to those obtained for masked serial displays in Experiment I (38.0% versus 33.5%). Although the "masked normal-order" condition in this experiment contained few observations (five words per subject) the differences in identification accuracy were highly stable across subjects. The 17.3% difference in accuracy between the normal and random masked conditions was significant ($t = 2.9$, $p > .01$). The difference is virtually identical to that observed in the unmasked condition. Again, serial display in nonstandard order confronts the subject with a kind of anagram task, in addition to

the task of individual letter identification, and his performance falls accordingly.

(5) When identification levels are broken down by word length, different patterns emerge in the masked and unmasked conditions. In the unmasked random conditions, accuracy is the same for three and-four letter words (81.0% versus 80.1%). Five letter words are identified somewhat less well (68.1%). The difference between the five-letter score and the poorer three and four-letter scores is significant ($t = 4.52$ $p > .001$). This difference probably represents the effect of eye movements, as described earlier. In the masked conditions, three-letter words are identified markedly better than four-letter words, and four-letter words better than five-letter words (37.1%, 20.4%, 8.3% respectively). No significance test was performed because the difference had not been predicted, and because the independence of the test from others performed on the data would be questionable. This difference may be due to the fact that unscrambling short words is easier than unscrambling longer ones.

* * * * *

Experiment III: "Orders of Approximation" Study

A. Method

The purpose of this study was to determine whether non-word strings bearing a definite statistical relationship to English would show the masking or parallel processing effect obtained with words.

The non-word strings were zero, second and fourth-order "approximations to English". They were constructed by a technique originally devised by Shannon (1948) and since used in a variety of psychological experiments (e.g. Miller, Bruner and Postman, 1954). Zero-order approximations are simply random strings of letters. Second-order approximations are constructed as follows: a letter is selected at random from any book in English. The page is turned, and another instance of that letter is located. The letter <u>following</u> the new instance is selected as the second letter in the string. The page is turned again, an instance of the new letter found, and the letter following it selected as the third letter in the string, etc. Thus each letter after the first is selected according to the probability that it follows the first in printed English. A fourth-order approximation is defined analogously as a string in which each letter is selected according to the probability that it follows the preceding three letters in printed English. In practice, the book technique is clumsy for constructing fourth-order approximations, so an alternative means of estimating probabilities is used: a reader of English is shown a letter and asked to select the second; a second reader is shown the first two and asked to select a third; a third reader is shown the first three and asked to select a fourth, and each succeeding letter is chosen by showing the preceding three letters to a subject who selects the next letter.

One hundred approximations of each of zero, second and fourth order were constructed. In addition, a group of one hundred common

English words were selected. Each group of stimuli was divided into four subgroups -- one shown with a mask at 50 msec. per letter, one with a mask at 200 msec., one with no mask at 50 msec. and one with no mask at 200 msec. Thus there were 25 words or strings in each experimental condition. Within these blocks of 25, there were five of each length from four to eight letters. The complete list of words and strings is given in Appendix C.

This experiment proved to be surprisingly difficult to perform correctly and occupied a disproportionate amount of time in the total research project. Some of the problems encountered, and their solutions, are mentioned here because they are highly relevant for other investigators who might be interested in replicating or extending the results reported here.

The basic difficulty was signalled by a failure, in early versions of the "approximations" experiment, to replicate the results reported earlier by the author (Travers, 1970; 1973). A comparison of Figure 2, which presents the author's previous results, and Table 3, which presents the results of one of several early attempts at the "approximations" study illustrates the problem. In Table 3 the zero-order approximations (random strings) show a pattern somewhat similar to that shown by words in Figure 2: the mask has a large effect on identification accuracy; the increase in accuracy with increased exposure duration is greater in the masked condition than in the unmasked condition. This outcome stands in sharp contrast to the results obtained with random

TABLE 3

Experiment III: Data From One Selected Early Version of the "Orders of Approximation" Study[1]

Percent of Letters or Words Identified Correctly as a Function of String Type, Letter Exposure Duration, and Masking Condition.

	MASKED		UNMASKED	
	50 msec per letter	200 msec per letter	50 msec per letter	200 msec per letter
Zero-Order Approximations[2]	21%	59%	42%	65%
Second-Order Approximations[2]	24%	63%	51%	74%
Fourth-Order Approximations[2]	25%	67%	51%	74%
Words[3]	31%	67%	0%	43%

[1] In this particular study, 12 subjects were run. Each subject identified all stimuli. The stimulus onset marker was a dot located at the center of the field. Letters measured 5/32" by 7/32".

[2] Data for non-word strings are scored in terms of percent of letters correct.

[3] Data for words are scored for whole words correct.

strings in the earlier studies, which found virtually no differences attributable to masking. The data for words in the "approximations" study also contradict those obtained for words in previous research: identification levels in the "unmasked" condition show a marked increase with increased exposure duration, and masked words are never identified as accurately as unmasked words, even at exposure durations long enough to allow a substantial amount of cover letter-naming. Levels of identification in all conditions are much lower than those in the earlier study. Thus the outcome of this early "approximations" study challenges the findings and, a fortiori, the theory offered in the author's previous work.

However, there was reason to place greater faith in the previous results. Not only were those results based on a larger number of subjects and of observations per subject, but they also had been partially replicated in Experiments I and II, described above. In particular, the very low levels of word identification obtained in the "approximations" study had not been found in the overlap and order variation studies. Therefore the procedures of the early versions of the approximations study were examined closely to determine whether some aspect of the method, casually varied from the earlier studies, might account for the differences in the results. It would be tedious to report on all of the variations undertaken in connection with this effort. However, their results can be summarized in the following methodological caveats to anyone interested in pursuing the technique further:

(1) The total visual angle subtended by word displays must be small enough to allow comfortable apprehension of the entire word at one fixation.

(2) The onset of stimuli must be signalled by markers which allow the subject to focus his eyes properly. In the present, successful studies, pairs of colons (: :) were used, bracketing the space in which the word appeared. One conventional signal, a dot at the center of the display area, produces inefficient eye movements; with such a signal the first letter of the word appears to the left of the fixation point, tending to provoke a leftward eye movement which causes the subject to miss part of the rightward-moving display. (This factor probably accounted for the low word recognition levels in the particular experiment described above.) It is also crucial that the onset signals precede the displays immediately; if too much time elapses between the onset signal and the display, the subject's eyes may wander.

(3) Long experiments -- over half an hour, or about 100 stimulus strings -- produce fatigue which depresses performance in all conditions, sometimes obscuring experimental differences. This difficulty is particularly acute for non-word strings, which bore subjects.

(4) Stimulus strings with a given type of structure must be displayed in blocks, allowing subjects to form an appropriate set. If, for example, random strings are interspersed with words or other structured strings, the subject may adopt a serial processing strategy

necessary for the random strings but inappropriate for words or structured strings.

In the final version of the "approximations" experiment, thirty-two subjects were run, eight for each of the "orders of approximation". Each subject thus identified 100 stimuli. Colons were used as markers, and the displays were of the size (5/32" by 7/32") mentioned in the general methods section.

B. Results

The results of the approximations study are shown in Table 4 and Figure 7. The data for strings recognized in their entirety replicate the earlier results for words and random strings fairly well. Words show a clear parallel processing effect; quantitative results for the 50 msec. exposure duration match those of the earlier study closely, although unmasked words at 200 msec. are identified somewhat more accurately than in the previous works (perhaps because the study was brief enough to prevent fatigue). The data on identification of random strings show a clear absence of any masking effects, also the pattern obtained in earlier studies.

Using the Data-Text statistical package for the IBM 360 computer, a five-way analysis of variance was performed, with the number of strings identified as the dependent variable. Order of approximation was used as a fixed independent within which subjects were nested. Masking condition, exposure duration and string length were used as fixed independent variables, crossed by the subject variable within each order of

TABLE 4

Experiment III: Final "Approximations" Study

Percentage of Strings and Letters Correct as a Function of Order of Approximation, Masking Condition, Exposure Duration and String Length.

A. STRINGS CORRECT

1. Zero-Order

MASKED

String length: (letters)	50 msec per letter						200 msec per letter					
	4	5	6	7	8	ALL	4	5	6	7	8	ALL
	3%	0	0	0	0	0.5%	70%	38	15	10	3	27.0%

UNMASKED

String length: (letters)	50 msec per letter						200 msec per letter					
	4	5	6	7	8	ALL	4	5	6	7	8	ALL
	20%	5	3	0	0	5.5%	60%	35	15	10	3	24.5

2. Second-Order

MASKED

String length: (letters)	50 msec per letter						200 msec per letter					
	4	5	6	7	8	ALL	4	5	6	7	8	ALL
	20%	3	3	0	0	5.0%	70%	63	38	23	5	39.5%

UNMASKED

String length: (letters)	50 msec per letter						200 msec per letter					
	4	5	6	7	8	ALL	4	5	6	7	8	ALL
	25%	13	0	0	0	7.5%	68%	53	38	13	13	36.5

3. Fourth-Order

MASKED

String length: (letters)	50 msec per letter						200 msec per letter					
	4	5	6	7	8	ALL	4	5	6	7	8	ALL
	23%	3	3	0	0	5.5%	65%	58	40	15	15	30.5%

UNMASKED

String length: (letters)	50 msec per letter						200 msec per letter					
	4	5	6	7	8	ALL	4	5	6	7	8	ALL
	45%	10	10	5	0	14.0%	70%	70	35	15		44.0

4. Words

MASKED

String length: (letters)	50 msec per letter						200 msec per letter					
	4	5	6	7	8	ALL	4	5	6	7	8	ALL
	65%	63	68	65	58	63.5%	85%	83	85	83	75	82.0%

UNMASKED

String length: (letters)	50 msec per letter						200 msec per letter					
	4	5	6	7	8	ALL	4	5	6	7	8	ALL
	98%	90	75	93	75	86.0%	98%	100	95	85	93	94.0

TABLE 4 -- CONTINUED

B. LETTERS CORRECT

1. Zero-Order

	MASKED												UNMASKED											
	50 msec per letter						200 msec per letter						50 msec per letter						200 msec per letter					
String length: (letters)	4	5	6	7	8	ALL	4	5	6	7	8	ALL	4	5	6	7	8	ALL	4	5	6	7	8	ALL
	64%	54	32	38	35	42.1%	96%	87	81	68	66	76.8%	78%	67	63	43	43	54.1%	93%	84	76	73	68	76.5%

2. Second-Order

	MASKED												UNMASKED											
	50 msec per letter						200 msec per letter						50 msec per letter						200 msec per letter					
String length: (letters)	4	5	6	7	8	ALL	4	5	6	7	8	ALL	4	5	6	7	8	ALL	4	5	6	7	8	ALL
	78%	59	54	43	44	52.9%	97%	94	85	80	76	84.3%	84%	77	62	58	51	63.3%	96%	93	89	80	74	84.6%

3. Fourth-Order

	MASKED												UNMASKED											
	50 msec per letter						200 msec per letter						50 msec per letter						200 msec per letter					
String length: (letters)	4	5	6	7	8	ALL	4	5	6	7	8	ALL	4	5	6	7	8	ALL	4	5	6	7	8	ALL
	76%	63	66	51	48	58.7%	95%	93	89	80	77	84.9%	88%	73	73	59	58	67.7%	98%	96	85	86	81	87.7%

4. Words

	MASKED												UNMASKED											
	50 msec per letter						200 msec per letter						50 msec per letter						200 msec per letter					
String length: (letters)	4	5	6	7	8	ALL	4	5	6	7	8	ALL	4	5	6	7	8	ALL	4	5	6	7	8	ALL
	89%	92	84	85	74	83.4%	97%	98	95	95	90	94.4%	99%	96	92	97	87	93.4%	99%	100	98	95	99	98.2%

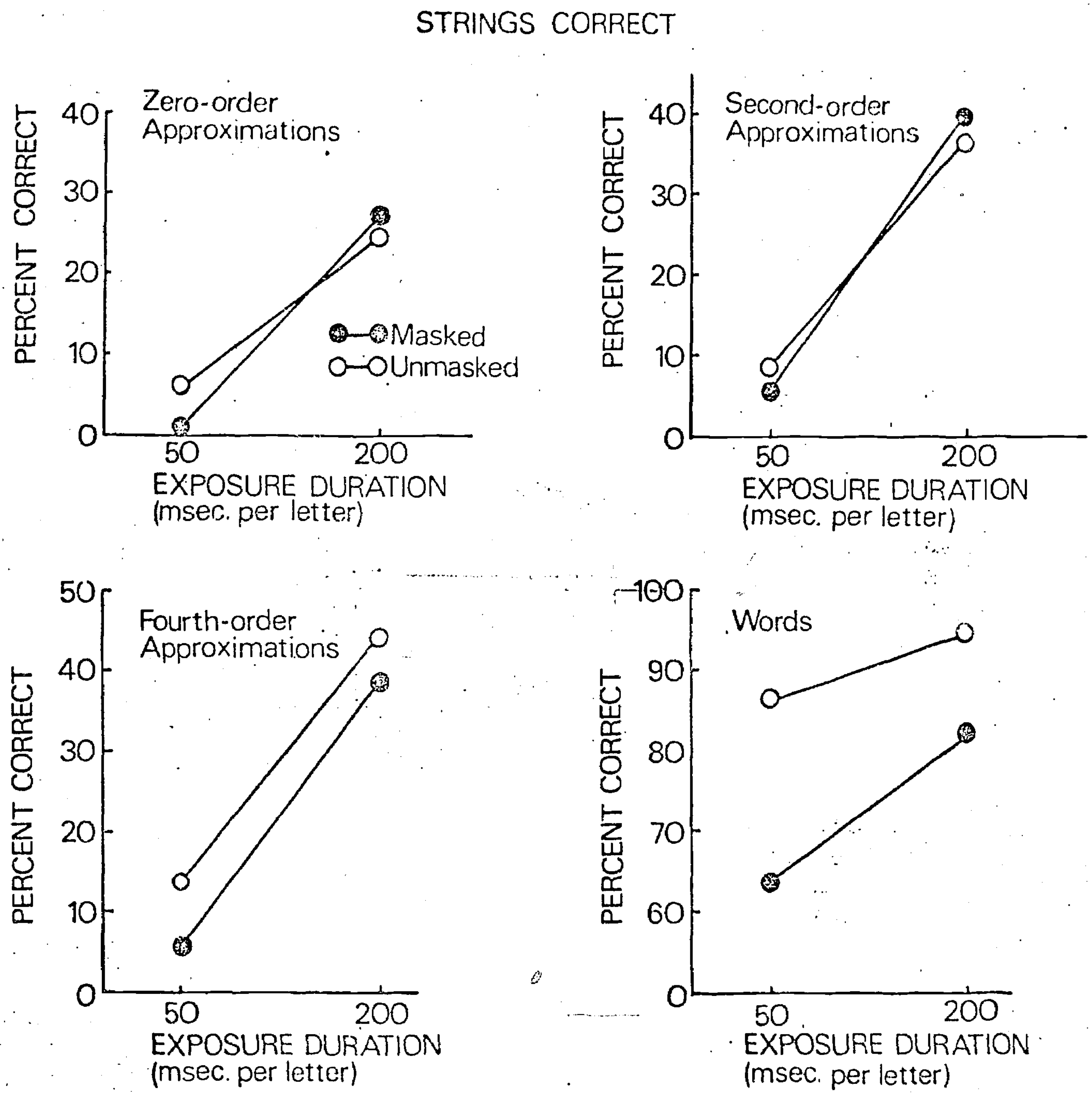

Figure 7A. Results of "Approximations" Study: Percentage of Strings Correctly Identified as a Function of Order of Approximation, Masking Condition and Exposure Duration.

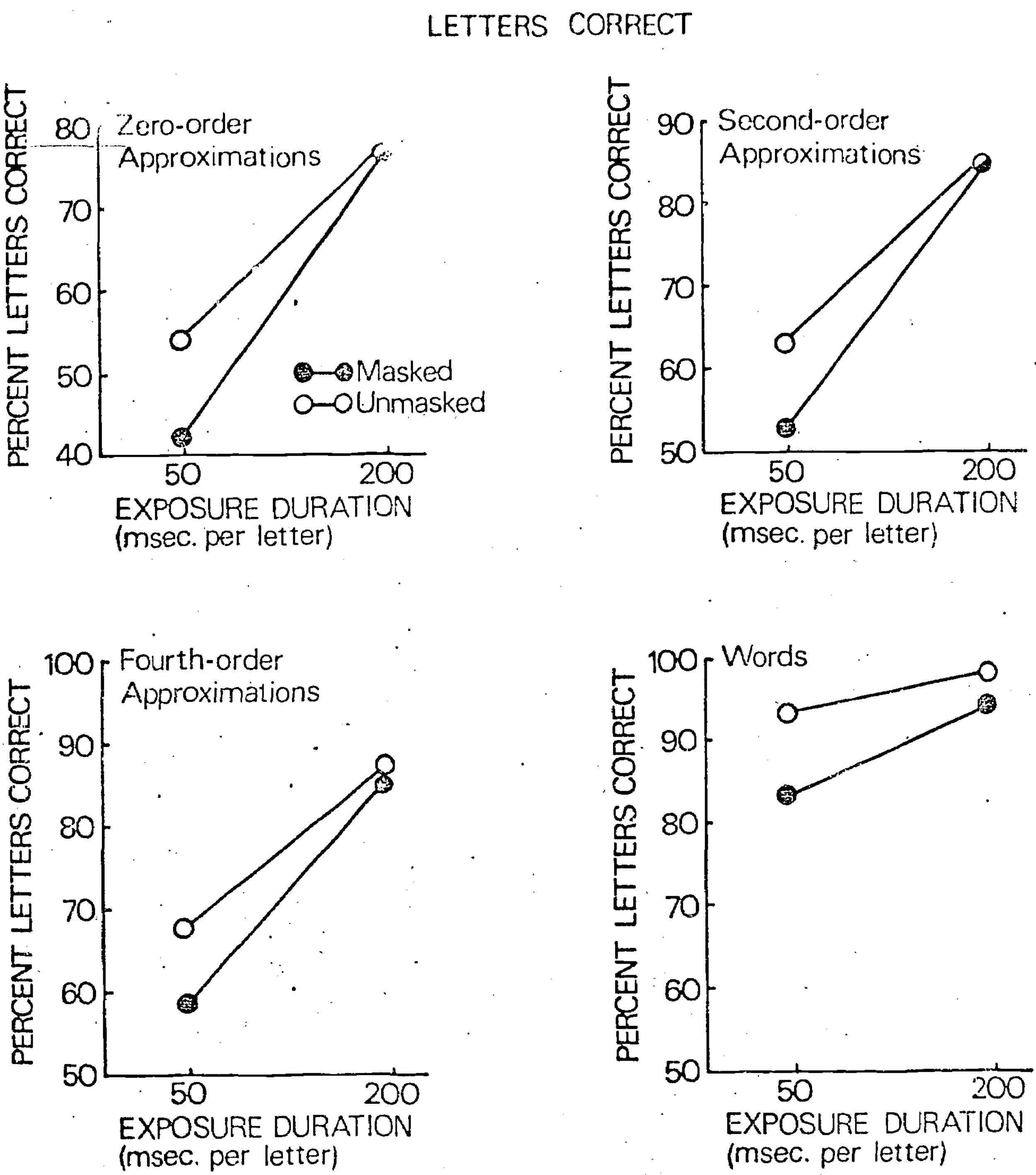

Figure 7B. Results of "Approximations" Study: Letters Correctly Identified as a Function of Order of Approximation, Masking Condition and Exposure Duration.

approximation. Subjects were treated as a random independent variable. (This is the usual treatment for repeated measures on the same set of subjects.) The main effect for order of approximation was highly significant ($p > .001$). A following test of differences beteween all possible pairs of "approximations" was then performed, using the Newman-Keuls procedure as described in Winer (1962, pp.77-81). This analysis revealed that words were recognized more accurately than all non-word strings ($p > .01$ for all comparisons) but that differences among the non-word strings were all non-significant. The main effects for masking, exposure duration and length were all significant ($p > .001$ in every case). The masking-by-exposure duration interaction reached a significance level of .03, indicating the tendency of differences produced by masking to be greater at more rapid exposure durations. There were also significant interactions between order of approximation and masking condition ($p > .003$) and order of approximation and string length ($p > .001$). The first of these interactions clearly reflects the tendency of the masking effect to grow as strings become more wordlike; the second indicates that length matters less for words than for non-word strings. (As indicated in Table 4, length has little effect on recognition of words, whereas increasing length is associated with marked decrements in performance for non-word strings.)

The data for letters identified differ in one important respect—from both previous results and the data on string identification just described: the effects of the mask are as strong for non-word strings as for words, especially at the 50 msec. exposure duration. This observation was confirmed by a 5-way analysis of variance, exactly parallel to the one described above, except that the dependent variable was the percentage of letters correct, rather than the number of strings. The main effects for both Order of Approximation and Masking were highly significant ($p > .001$) but their interaction was nonsignificant ($p > .5$).

One partial interpretation of this pattern of results is that non-word strings, even randomly generated non-word strings, incorporate sections which resemble English words. Thus, even random strings permit a certain amount of parallel processing and may therefore show a masking effect. However, this explanation fails to account for the fact that the effect of the mask on letter identification is as large for random strings as for English-like strings and for words. Since <u>string</u> identifications show a masking effect only for words, it is clear that factors other than letter identification are operating to produce the pattern of results in the case of strings. Further theoretical work is needed to explain fully the relationship between the two different identification measures.

The present results reinforce the earlier conclusion that words are processed differently from unstructured strings; the present results also suggest that the rough degrees of "Englishness" embodied in different orders of approximation do not capture effectively the features of English structure which allow skilled readers to process words in parallel. Figure 7 does show a tendency for the pattern of results to become more "wordlike" with higher orders of approximation to English; however, even fourth-order approximations are markedly different from words in overall recognition levels and somewhat different in their susceptibility to masking. Clearly, a more refined conception of word structure is needed, if the relations between structure and cognition are to be understood.

* * * * *

Experiment IV: Structure-Pronounceability Pilot

A. Method

The "Structure-Prnounceability" pilot study was a preliminary attempt to determine whether the masking or parallel processing effect can be obtained with pronounceable non-word strings, high-frequency non-word strings or both. Non-word strings had shown modest parallel processing effects in Experiment III; it was possible that some subset would show stronger effects, perhaps revealing more clearly the mechanisms involved in the effect.

The stimuli used in the experiment were 64 trigrams, divided into four groups:

(1) high frequency, high pronounceability;

(2) high frequency, low pronounceability;

(3) low frequency, high pronounceability;

(4) low frequency, low pronounceability.

Frequencies were assesed by a computer count of 5 million characters of printed English, provided by Dr. Donald Olivier. High frequency trigrams all appeared at least 1,000 times in the 5-million character sample, with a mean of 1,780 occurrences. Low-frequency trigrams all appeared less than ten times in the sample, with a mean of 3.3 occurrences. Pronounceability was assessed by having three subjects rate all items on a four-point scale. High-pronounceability items were unanimously ranked as falling into the top two categories, and low-pronounceability items were unanimously ranked in the bottom two. A list of trigrams falling in the four stimulus categories is provided in Appendix D.

Four of the trigrams in each pronounceability-frequency group were then shown to subjects one letter at a time, with a mask, at 50 milliseconds per letter. A second group of four was shown with a mask at 50 msec., and a final group at 200 msec. with no mask. The sixteen trigrams in each display point were shown as a block; the order of blocks was counter-balanced across subjects. A total of four subjects were run.

B. Results

Results were scored for trigrams fully correct and for number of letters correct. Both sets of data are given in Table 5. Though the study was done on a small scale and therefore cannot be regarded as conclusive, the data are clear and consistent: there is no difference in the pattern of results across frequency-pronounceability combinations. For all cases, a pattern may be observed which resembles that obtained for words in the author's earlier work (see Figure 2). Masked stimuli are identified poorly at 50 msec. per letter; at 200 msec. per letter,

TABLE 5

Results of Pronounceability-Frequency Pilot

A. Trigrams Correctly Identified as a Function of Pronounceability, Frequency, Masking Condition and Exposure Duration

	1. High Frequency High Pronounceability: 50 msec per letter	200 msec per letter	2. High Frequency Low Pronounceability: 50 msec per letter	200 msec per letter
Unmasked	11 (69%)	14 (88%)	12 (75%)	16(100%)
Masked	6 (38%)	16(100%)	3 (19%)	15 (94%)

	3. Low Frequency High Pronounceability: 50 msec per letter	200 msec per letter	4. Low Frequency, Low Pronounceability: 50 msec per letter	200 msec per letter
Unmasked	9 (56%)	16(100%)	11 (69%)	15 (94%)
Masked	3 (19%)	13 (81%)	2 (13%)	16(100%)

B. Letters Correctly Identified as a Function of Pronounceability, Frequency, Masking Condition and Exposure Duration.

	1. High Frequency High Pronounceability: 50 msec per letter	200 msec per letter	2. High Frequency Low Pronounceability: 50 msec per letter	200 msec per letter
Unmasked	43 (90%)	46 (96%)	44 (92%)	48(100%)
Masked	29 (60%)	48(100%)	27 (56%)	47 (98%)

	3. Low Frequency High Pronounceability: 50 msec per letter	200 msec per letter	4. Low Frequency Low Pronounceability: 50 msec per letter	200 msec per letter
Unmasked	39 (81%)	48(100%)	43 (90%)	47 (98%)
Masked	31 (65%)	45 (94%)	31 (65%)	48(100%)

a rate slow enough to permit serial letter identification, they are identified about as easily as unmasked strings. Unmasked stimuli are identified far more accurately than masked at 50 msec. per letter; the gains between 50 and 200 msec. are modest for unmasked strings. (In the case of words, the gain was zero, as shown in Figure 2.)

The equality of results across conditions suggests that neither frequency of occurrence nor pronounceability has much to do with the existence of the parallel processing effect. However, this interpretation must be viewed with caution, for at least two reasons: (1) all the strings used in the experiment were trigrams. There is some evidence that such small clusters of letters can be processed in parallel even when they are randomly selected (Sperling, 1967). (2) In order to balance frequencies and pronounceabilities across all experimental conditions, it was necessary to restrict the range of frequencies and pronounceabilities which could be used. For example, zero-frequency trigrams could not be used in the two low-frequency conditions because it is extremely difficult to find zero-frequency, highly pronounceable trigrams. Since the full range of frequencies and pronounceabilities could not be explored, the null generalization must be restricted to only part of the frequency and pronounceability spectra. This fact is particularly important with respect to the low-frequency, low pronounceability cell. It might seem puzzling that the data for this condition does not resemble those for the random strings in Figure 3. The somewhat "word-like" pattern for this condition may be due to the fact that even the low frequency, low pronounceability strings possessed considerable resemblance to English on several dimensions.

It may appear that the first of these problems could have been offset easily by using longer strings. However, reliable frequency counts are not available for clusters larger than trigrams. Therefore a measure of statistical "Englishness" other than sheer frequency of occurrence must be used. Dr. Donald Olivier has invented such a measure, one constructed in a manner somewhat analogous to the "orders of approximation" discussed earlier.

Olivier's measure defines the "Englishness" of a letter string $L_1L_2L_3 \ldots L_n$ as

$$E = P(\text{space}) \cdot P(L_1|\text{space}) \cdot P(L_2|\text{space},L_1) \cdot P(L_3|L_1,L_2) \cdots P(L_n|L_{n-2},L_{n-1})$$

where all of the "P's" are probabilities in printed English, and $P(L_n|L_{n-2},L_{n-1})$ means "the probability that the letter that appears in the n^{th} position in the string will follow the two letters in position n-2 and n-1. These probabilities may be estimated from letter cluster frequencies derived from Olivier's computer count of 5 million characters of printed English. For example,

$$P(L_n|L_{n-2},L_{n-1}) \triangleq \frac{F(L_{n-2},L_{n-1},L_n)}{F(L_{n-2},L_{n-1})}$$

where $\triangleq$ means " is estimated by " and the "F's" are frequencies in English. That is, the probability that letter L_n follows the diagram $L_{n-2}L_{n-1}$ is estimated by the frequency of the trigram $L_{n-2}L_{n-1}L_n$ divided by the frequency of the leading diagram, $L_{n-2}L_{n-1}$.

five -

A large number of six-letter strings were constructed, using Olivier's raw frequency counts as a rough guide to "Englishness" and intuition as a rough guide to pronounceability. These strings were then run through a computer program which calculated Olivier's Englishness measure for each. Pronounceability was checked by having subjects rate each string on a four-point scale. By this method a smaller set of stimulus strings was selected from the original set. The new stimuli possessed the desired pronounceability and frequency characteristics and were not limited to trigram length. (The strings are shown in Appendix E.) Unfortunately this work was completed at the very end of the present research project, and there was no opportunity to use the new strings in a masking study to determine whether the parallel processing effect varies with string type. This remains work for the future.

* * * * *

Experiment V: Phrase Pilot

A. Method

As outlined in the introduction, the purpose of the phrase pilot was to determine whether the masking or parallel processing effect operates over grammatical units larger than words.

Thirty-two commonplace three-word phrases were selected arbitrarily. These were shown to eight subjects, one letter at a time. Eight phrases were displayed with a mask at 50 msec. per letter, eight with a mask at 200 msec., eight without a mask at 50 msec. and eight without a mask at 200 msec. Phrases ranged in length from 11 to 19 letter-positions (counting the two internal spaces as letters), and average length was approximately controlled across visual conditions. The phrases used in the study are shown in Appendix F.

Phrases shown under the same visual conditions, i.e. the same masking conditions and exposure durations, were shown in blocks of eight. The order of blocks was counter-balanced across subjects.

B. Results

The data were scored in terms of the number of phrases reported correctly in their entirety, and of the number of words within phrases reported correctly. Both sets of results are shown in Table 6.

Neither the phrase nor the word data show evidence of the parallel processing effect observed in other studies. In both cases there is a strong masking effect: unmasked phrases are identified more accurately than masked by a 29.4% margin overall; unmasked words are identified better than masked words by a 30.7% margin. However in neither case does the mask show its effects selectively at brief exposure durations (the parallel processing effect). The curves for masked and unmasked displays are approximately parallel for both words and phrases.

Similarly, exposure duration shows a marked effect on recognition, even without a mask. Unmasked phrases shown at 300 msec. per letter are identified more accurately than those shown at 50 msec. by a 16.0% margin. For unmasked words, exposure duration creates a 32.2% differential. Thus phrases are not being retained in iconic memory and

TABLE 6

Experiment V: Phrase Pilot

Percentage of Words and Phrases Correctly Identified as a Function of Masking Condition and Exposure Duration.

MASKED				UNMASKED			
50 msec per letter		200 msec per letter		50 msec per letter		200 msec per letter	
Words	Phrases	Words	Phrases	Words	Phrases	Words	Phrases
19.8%	1.6%	36.5%	14.1%	47.9%	29.7%	79.7%	45.7%

processed as wholes.

In sum, the present data give no support to the hypothesis that skilled readers process whole phrases at once. Though eye-movement and other data (e.g. Mehler, Bever and Carey, 1967; Schlesinger, 1964) may suggest that whole phrases can be processed at a single fixation, the present data suggest that the internal cognitive scan of letters within words is serial. Of course, accepting the null hypothesis is not equivalent to demonstrating its truth; it is entirely possible that different subjects, or a different procedure, would give different results. Nevertheless the negative outcome of the phrase pilot must be viewed in the context of rather strong and consistent positive findings for individual words.

CONCLUSIONS

Experiments I and II yielded clearcut results which support the conclusions of previous work on parallel and serial processes in the recognition of words and letter strings: skilled readers have learned to process words as perceptual wholes, or, at least, letter clusters within words can be "chunked" and processed in parallel. Non-word letter strings, especially random strings, cannot be chunked as effectively and therefore tend to be processed in series. These conclusions further suggest that the process of learning to read entails an abstract and intriguing form of perceptual learning: the child learns structural rules which facilitate processing of certain letter clusters, yet these rules do not depend on the specific appearance of letters; they can be applied to a wide variety of typefaces and handwriting styles as evidenced by the fact that subjects were able to apply them to totally novel computer displays. The results of Experiments I and II are incorporated in a research report now in preparation for submission to a psychological journal, probably Cognitive Psychology.

Attempts to refine and extend these basic conclusions met with less success, however. Experiment III provided at best very weak support for the expectation that parallel processing effects would apply to non-word strings bearing a structural resemblance to English. Experiment IV gave no evidence at all that the effect applied selectively either to high-frequency trigrams or to highly pronounceable trigrams. As pointed out in an earlier section, the outcome of this particular experiment may be due to the length of the strings involved. Experiment IV gave no evidence that the parallel processing effect operates over grammatical units larger than words, although this negative result may be due to limitations of the serial display technique.

Of the many questions raised by these attempts to extend the basic conclusions, perhaps the one which offers the most promise for future exploration with the present technique is that concerning the possible statistical versus phonological bases of the parallel processing effect (a problem treated indirectly in Experiment III and directly in Experiment IV). It is important to determine whether parallel processing of words is made possible because experienced readers have seen certain clusters of letters in frequent conjunction, or because certain clusters form pronounceable units which can be encoded succinctly. Experimental materials have been prepared for a more extensive future exploration of this question.

A final word should be said concerning the implications of this research for the teaching of reading. Basic research on cognitive processes in reading may clarify the nature of the skilled reader's ability and thereby may clarify the task facing the teacher of reading. Nevertheless it would be absurd and disingenuous to claim or expect that work of this type will lead directly to improvements in reading instruction. In fact, it is important to avoid premature attempts to link findings such as those reported here to particular philosophies of reading instruction. For example, the emphasis throughout this report on apprehension of words as single units should not be construed as support for the "whole word" approach to teaching reading. While the end product of the learning process is an individual who apprehends words as wholes, it may still be true that the best way to achieve that end state in practice with the phonological or spelling patterns of the language. Only direct experimentation on the teaching and learning of reading can elucidate the connections between the cognitive strategies of the mature reader and learning strategies in the child.

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APPENDIX A: Stimulus Words for Temporal Overlap Study

(Numbers following each word represent frequencies in one million words of printed English.)

A. Unmasked Displays

1. Serial Display		2. Digram Overlap		3. Trigram Overlap		4. Simultaneous Display	
hole	58	ends	66	wait	94	cost	229
held	264	food	147	hair	148	clay	100
task	60	wind	63	news	102	roof	59
snow	59	wish	110	hung	65	vast	61
moon	60	shot	112	laws	88	save	62
favor	78	lower	124	corps	109	phase	72
score	66	fixed	87	labor	149	teeth	103
taste	59	chair	66	eight	104	shore	61
faith	111	piece	129	drawn	70	range	160
space	184	dance	90	beach	61	aware	84
impact	67	unless	101	record	137	murder	75
beauty	71	demand	102	pretty	107	smiled	71
mother	216	spring	127	crisis	83	couple	122
travel	61	events	101	attack	105	proper	95
search	66	career	67	stared	60	series	130
primary	96	capital	85	quality	114	nuclear	115
removed	75	sitting	96	applied	106	attempt	95
advance	60	herself	125	current	104	parents	91
minutes	196	fifteen	56	kitchen	90	covered	104
aspects	64	evening	133	address	77	entered	98
somewhat	127	attorney	65	religion	119	repeated	59
prepared	102	campaign	81	entrance	57	agencies	62
internal	62	argument	63	everyone	94	remained	105
directly	141	reaction	124	opponent	57	expected	187
domestic	63	thousand	139	research	171	occurred	67
Mean Frequencies:	98.6		98.4		98.8		98.7

Mean Frequencies by word length:

Four-letter: 97.4 Five-letter: 98.6 Six-letter: 98.6

Seven-letter: 98.7 Eight-letter: 98.6

Overall Mean Frequencies by Masking Condition:
Unmasked: 98.6 Masked: 98.7

Overall Mean Frequencies by Degree of Overlap:

Serial: 98.6 Digram: 98.5 Trigram: 98.8 Simultaneous: 98.6

APPENDIX A -- CONTINUED

B. Masked Displays

5. Serial Display

song	70
game	124
flat	67
base	91
list	133
glass	99
theme	55
scale	60
level	213
forth	71
recent	179
marked	85
narrow	63
twenty	80
appeal	77
measure	91
picture	162
opinion	96
affairs	84
fashion	69
universe	71
whatever	112
increase	195
maintain	60
solution	59
Mean Frequencies:	98.6

6. Digram Overlap

heat	97
desk	65
fear	127
army	121
neck	81
mouth	103
funds	95
plant	125
judge	77
civil	91
master	72
caught	98
column	71
spirit	182
escape	65
explain	64
station	105
prevent	83
treated	75
medical	162
somebody	57
soldiers	56
together	267
exchange	70
critical	58
Mean Frequencies:	98.7

7. Trigram Overlap

soft	61
soon	199
mine	59
trip	81
thin	92
river	165
drink	82
check	88
guess	56
spent	104
forest	66
corner	115
choice	113
design	114
famous	89
attempt	95
concept	85
average	130
patient	86
suppose	97
separate	79
aircraft	70
appeared	135
addition	142
dominant	65
Mean Frequencies:	98.7

8. Simultaneous Display

test	119
mass	110
none	108
seek	69
lips	69
break	88
story	153
stone	58
press	127
thick	67
bottom	88
market	155
unique	58
middle	118
weight	91
dollars	97
shelter	70
various	201
conduct	55
weapons	61
shoulder	61
received	163
hospital	110
indicate	80
moreover	88
Mean Frequencies:	98.6

APPENDIX B: Stimulus Word List for Experiment II --

Temporal Order Variation Study

(Numbers following each word represent frequencies in one million words of printed English.)

A. Masked - Random

low	174	bed	127	duty	61	rain	70	break	88	types	116
van	32	sun	45	bare	29	goal	60	wrote	181	claim	98
red	197	aim	37	size	138	wash	37	quiet	76	drugs	28
try	140	gas	98	mean	199	ways	128	threw	46	clear	219
box	70	sat	158	pick	55	sing	34	bring	158	lower	123
ago	246	six	220	body	276	read	173	spite	56	cloth	43
net	132	cry	48	coal	32	ours	27	yards	64	panel	31
ear	29	oil	93	grew	64	land	217	wrong	129	train	82
fed	42	bus	34	film	96	atom	37	study	246	table	198
leg	58			milk	49	barn	113	loans	32	maybe	134
dog	75			fair	77	whom	146	alone	195	blame	34
						farm	125	drunk	37	avoid	58
Σ= 2055		μ= 102.75		Σ=2243		μ = 97.52		Σ= 2472		μ= 103.00	

B. Masked - Normal

eat 61 cap 27 gun 118 tax 197 Σ= 403 μ= 100.75	turn 233 Σ= 233 μ = 233	
Masked 3-letter Σ= 2458 μ= 102.42	Masked 4-letter Σ= 2476 μ = 103.17	Masked 5-letter Σ= 2472 μ= 103.00 Masked Σ = 7406 μ = 102.86

APPENDIX B -- CONTINUED

C. Unmasked - Random

sky	58	sir	95
act	283	sun	112
law	299	mad	39
due	142	art	208
wet	53	bay	57
car	274	hot	130
led	132	eye	122
bug	70	fat	60
age	227	kid	61
gay	30	pat	35
hat	56	cut	192
yes	144	fit	75
bit	101	ten	165
arc	41	sin	53
fun	44	ask	128
arm	94	joy	40
run	212	bar	82
cow	29	lot	127
jet	29	die	73
bag	42	net	34
nor	195	sad	35
sea	95	boy	242
six	84	top	204
pot	28	tea	28
guy	51	bad	142
lay	139	lie	59
row	35	air	257
mud	32	via	48
aid	130	fly	33
fig	72	era	30

Σ = 6187

N = 60

μ = 103.12

foam	37	nice	75
sick	51	sent	145
spot	57	easy	127
blow	33	note	127
navy	37	race	103
pink	48	near	198
goes	89	cost	229
rule	73	game	123
step	131	ship	83
deal	142	chin	27
risk	54	wish	110
move	171	gift	33
list	133	main	119
thin	92	hate	42
rode	40	true	231
sang	29	jury	67
rate	209	rise	102
wide	125	weak	32
pike	41	polê	58
post	84	drew	68
blue	143	fund	62
wife	228	vice	41
tool	43	maid	31
gone	195	fish	35
band	53	line	298
wear	36	laws	88
flux	30	rest	163
lead	129	gain	74
wind	63	hurt	37
hear	153	post	281
tons	28	cost	45
lips	69	lord	93
show	287	sign	94
hard	202		
fear	127		
fire	187		

Σ = 7090

N = 69

μ = 102.75

drive	105	bread	41
favor	78	short	212
stule	98	minor	58
third	190	beach	61
hotel	126	stone	58
humor	47	strip	30
music	216	spent	104
words	274	metal	61
taken	281	blind	47
thank	36	phone	54
phase	72	money	265
brief	73	bound	42
grain	27	gives	112
makes	172	guilt	33
owned	34	parts	113
river	165	ranch	27
porch	43	image	119
begin	84	board	239
movie	29	black	203
hands	289	plant	125
finds	59	march	120
forms	128	moral	142
mines	28	boats	51
urged	35	women	195
model	77	porch	43
close	234	pride	42
comes	137	force	230
index	81	shade	28
focus	40	stage	174
mouth	130	trial	134
crowd	53	faces	72
works	130	hopes	48
sight	86	tears	34
fruit	35	anger	48
truck	57		
stick	39		

Σ = 7153

N = 70

μ = 102.19

Unmasked - Random

Σ = 20,430

N = 199

μ = 102.66

APPENDIX B -- CONTINUED

D. Unmasked - Normal

ice	45	won	68	wage	56	radio	120		
ran	134	cup	45	play	200	touch	87		
hit	115	job	238	soul	47				
key	88	win	55	Σ =	303	Σ =	207		
raw	43	dry	68	N =	3	N =	2		
son	166	pay	172	μ =	101.0	μ =	103.50		
Σ=	1237	Unmasked, 3-letter		Unmasked, 4-letter		Unmasked 5-letter		Unmasked	
N=	12	Σ=	7424	Σ =	7393	Σ =	7350	Σ =	22167
μ=	103.08	N=	72	N =	72	N =	72	N =	216
		μ=	103.11	μ =	102.68	μ =	102.22	μ =	102.63

APPENDIX C: Stimulus Words and Letter Strings for Experiment III

		Zero-Order Approximations	Second-Order Approximations	Fourth-Order Approximations	Words
Masked, 50 msec per letter	4.	UTIL	OYID	ARLI	FARM
		ZUXX	OCAL	ENIG	DUST
		XNXR	GHOP	RELA	ABLE
		FDLZ	NINK	ESTA	BOAT
		ICFP	PUED	RYLA	HALL
	5.	DCUUD	ISION	UETAS	COURT
		TONAO	NDIDI	MEADE	IMAGE
		XBHTQ	NTHED	TNTAE	SCENE
		LPWPJ	RFIMO	LYJAN	WATCH
		LVLMB	SURIT	DIFFO	TRAIN
	6.	QTUKJQ	ULLISN	ARLEYS	BESIDE
		DWYTVT	ORHEDE	DYLAST	BOTTLE
		WQJOXQ	SHELOO	MARRIN	STRONG
		NDWGJZ	AVEPAV	YGATED	SUMMER
		IUUBOC	IFADEY	XENIDE	MERELY
	7.	ZBSHQBX	LINDINO	EODALLS	FURTHER
		CCSCRBJ	NTHIMER	RINSUTE	ARTICLE
		AEFGWJD	UINGHER	SLIMEMB	FACTORS
		HKAYPZC	IMYNDRA	UMNILED	TROUBLE
		LLSLYRE	ROMANGH	DELLEEK	MACHINE
	8.	IQYJMPJV	SONTEVIN	RELAPITS	ANYTHING
		KGSYXWKR	ICTOWHEE	NSENTENT	OCCASION
		LDHUSCLE	SHEDERSN	CRENTEDD	CONTRACT
		IOEYKFXQ	XACEROOL	ESTAYLED	CONTINUE
		UPBDGHIO	STHOSTEA	TENTIONS	PROGRESS

APPENDIX C -- CONTINUED

		Zero-order Approximations	Second-Order Approximations	Fourth-Order Approximations	Words
Masked, 200 msec per letter	4.	RXQF	SUCA	ESTA	VOTE
		HOAW	IETH	ALGA	HOPE
		XZIR	EEVE	ENTI	REST
		OHTA	WSOW	TYTA	EASY
		LBHC	OLER	UEND	LIKE
	5.	XHOWU	ONGHU	YSTAT	HEAVY
		JJADQ	TANEM	NESSE	DOUBT
		QMZQV	ANDAR	TYRAT	TRIED
		TMZGG	ELESP	ONTYR	DAILY
		GCTLF	RYLON	CKRAT	STAFF
	6.	EYLWVC	OBLINS	RENEST	ISLAND
		SJPXIM	SALENT	ELIGAL	AFRAID
		EDTSDH	NGLERV	SSENTS	SINGLE
		MVISBJ	NDILLE	STRAMS	SECRET
		LMOAHS	GEATHA	EADELI	SQUARE
	7.	XYHPYTQ	ICATHE	ENTREPP	ACCOUNT
		CIEMGAB	INTHITH	YXODILL	RAPIDLY
		LPLIBMD	GNOSCICK	LOABLEM	SUPPORT
		WBVDOBJ	UREMOMU	IMERRIN	NEITHER
		WCXJVYU	UNUFORT	LCATTAN	FORWARD
				LSITHYET	AUDIENCE
	8.	JQWMNUMG	INEAMANT		
		IFHMSXUE	BYTINCKE	HERSAKEN	PHYSICAL
		QUYANQOH	SERIGATH	ATAAZEDS	BEHAVIOR
		SYNNENTN	SULICRIS	STIGHTIN	FEATURES
		FBGPAJWS	NTESANDL	EPINTAPS	PRACTICE

APPENDIX C -- CONTINUED

		Zero-Order Approximations	Second-Order Approximations	Fourth-Order Approximations	Words
Unmasked, 50 msec per letter	4.	RJHR	NTSL	FFRI	TOWN
		NOWH	LINO	TELE	WARM
		SNTH	NLYS	TANN	POST
		TZIU	ENTI	ESTA	BOOK
		TQDS	EACE	RNID	BUSY
	5.	EJJVQ	LDCHO	NYDAS	FIELD
		NFWJO	IFROT	EDRAM	RULES
		LLNDX	ANDEN	ANEED	GREEN
		NFNLH	NCERE	YSINO	INDEX
		YMFZP	RENKE	LSONO	DREAM
	6.	QPUSIC	ANKITH	TILTON	DANGER
		YBEDQW	SISYIN	IRENDS	REGION
		BKDAZT	NSDAPP	KSARAV	ACROSS
		WJTPMB	IRAIKE	EDDOWN	INCHES
		UBUJZW	RKLDST	STALEN	FILLED
	7.	AKCWVHN	ECHANDO	BBATTAN	POPULAR
		QYNJGWZ	IMPOUME	RCREARN	TENSION
		DTZNVVY	ANARERU	ENTERIN	SPECIAL
		QFYZIFD	REAMERT	LRANUES	RUNNING
		JVUPHHY	EARLEDA	ENTIANS	FAILURE
	8.	ZVEIQKPT	FEVERONY	ONIGAINT	RAILROAD
		BFFCSKRX	ANILITHO	SERVIRED	DIVISION
		MFODDHHZ	LINAMAMP	EDYTIENS	FAMILIAR
		EXOYNOSX	LLFULFAC	YERATTAN	REQUIRED
		MCSJTRSS	REIMYOW	OLYNNERE	EVIDENCE

APPENDIX C -- CONTINUED

		Zero-Order Approximations	Second-Order Approximations	Fourth-Order Approximations	Words
Unmasked, 200 msec per letter	4.	MOJL	SPOU	YSBY	COLD
		ZBWR	EAIS	THLI	LOST
		NPNJ	IOIU	STRI	EDGE
		ZVAH	NDIL	URNA	JURY
		KQDV	INOF	OPOL	BLUE
	5.	TWQDD	NOMPT	NEDPI	ROUND
		VPZBJ	EATHE	SERVI	TWICE
		MSPYU	ENEDE	LSONY	EQUAL
		VWVXD	NORIS	NELLO	SALES
		PTLVO	ERENT	NEDOI	BOARD
	6.	ISZGXV	HERISH	ERROWE	STRUCK
		FPDVEP	READAS	PBABBE	LEAGUE
		NRGPIN	LDYOLI	HONONE	NATURE
		PZTLUD	TASONE	PONNUP	GUESTS
		VURUHF	AGEAMA	EOLLIN	RESULT
	7.	MWOOEPX	SSIGIND	ECHANDS	DEFENSE
		RVBTSZZ	CILDOSA	ETTIEDL	CONTACT
		MGAAYKM	ATEALAT	EBRANGL	INCLUDE
		OEDAAXP	GINEITO	YOONANN	DECIDED
		GYVWZLC	LDENTHE	SATUREN	SILENCE
	8.	JDQQNXUQ	ATHSTIAN	SERVEARS	PERSONAL
		LKIHGLTC	EESTEHECH	NYONGORE	FINISHED
		CXTYJAPF	THANDEYE	TENTESTR	FUNCTION
		DMDADWWQ	ITHEDIEN	LYSANINE	OPPOSITE
		YAAARLVO	ELLALEAS	LYFANNEN	LITERARY

APPENDIX D: Trigram Stimuli for Experiment IV

CONDITION	High Frequency High Pronounceability		High Frequency Low Pronounceability		Low Frequency High Pronounceability		Low Frequency Low Pronounceability	
	Trigram	Frequency	Trigram	Frequency	Trigram	Frequency	Trigram	Frequency
Masked,	HED	1560	GHT	4563	BIP	4	XTS	7
50 msec	SPO	1187	NGL	1026	FOD	1	KCS	1
per letter	RIT	2410	TTL	1078	NIK	3	CGL	1
	LON	1826	CTU	1015	TEK	7	BBR	3
mean frequency		1745.8		1920.5		3.8		3.0
Masked,	ARL	1395	NTS	3098	MAV	6	WNP	3
200 msec	MAK	1159	TCH	1046	PEX	4	LCL	3
per letter	TAK	1153	NGS	1455	UKK	1	GHP	3
	RIN	3490	CTE	1413	JIF	2	HBE	2
mean frequency		1799.3		1753.0		3.3		2.8
Unmasked,	DED	2279	NDS	1643	APU	7	THG	2
50 msec	ICK	1058	RST	1789	GAK	1	FSK	3
per letter	PON	1455	NTR	2091	KAK	2	FFH	2
	ALI	2181	RCH	1367	WAP	3	FTN	7
mean frequency		1743.3		1722.5		3.3		3.5
Unmasked,	DIT	1400	MPL	2181	FAX	4	SCS	7
200 msec	GER	1609	MPA	1155	LEK	1	PCH	3
per letter	OTE	1490	RTH	1510	BAF	8	GBR	2
	LAN	2840	THR	2067	CEB	1	CGH	1
mean frequency		1834.8		1728.3		3.5		3.3

APPENDIX E: Examples of Letter Strings With High Pronounceability and Low Statistical Englishness*, Low Pronounceability and High Statistical Englishness.

High-Pronounceability, Low Englishness				Low Pronounceability, High Englishness			
String	-Log(P)	String	-Log(P)	String	-Log(P)	String	-Log(P)
IPOFU	19.427	IPRUK	15.887	MRSTS	6.438	ZWKST	9.957
UBOFI	19.966	UMFIK	16.633	THRMS	7.754	XYLKS	9.833
UCOTU	17.001	UMLOX	15.125	SSTSS	7.964	XYGNS	9.335
OSBIV	16.654	OMSUZ	15.019	CHNST	7.010	XYMUS	9.773
LYBIV	16.745	LYDOV	15.288	CHNNE	7.127	XYGMS	9.834
UCOKK	16.462	OOVOP	15.298	XYDNT	8.725	SPHLB	9.314
OMUBO	16.341	IVOMU	15.357	SPHST	8.604	PHLBS	9.592
AWOFO	16.603	IKAKK	15.501	SHMST	8.596	MRSHR	9.501
OOGMU	16.281	IKLUF	15.593	MRSHM	8.466	MRSTR	9.177
TYMSU	15.874	AWOTU	15.674	DRSTS	8.600	KRZKY	9.203
UBRYM	15.694			CHNSH	8.337	KHMST	9.727
NYDOB	15.401			CHNNS	8.014	CHNSP	9.496
						CHNSW	9.425
Mean -Log(P) = 16.219							

*"Englishness" is measured by Olivier's technique, as described in the "results" section for Experiment IV. The values given below are negative logarithms of the probabilities described in that section. Low values indicate high "Englishness".

APPENDIX F: Phrase Stimuli for Experiment V

1. 50 msec per letter, masked

a brave soldier
within the hour
a flying bird
under the table
a rainy day
out of bounds
a funny story
by a stream

mean length: 13.25 letters

2. 200 msec per letter, masked

the next page
beneath the papers
the first line
from the middle
the whole thing
with a smile
a white sheet
beyond the deadline

mean length: 14.9 letters

3. 50 msec per letter, unmasked

a true statement
beside the lamp
a grand view
before the rest
a light breeze
for one hour
the blue sky
in the room

mean length: 13.5 letters

4. 200 msec per letter, unmasked

two tall men
near the barn
this new book
against the tree
the other day
over the top
a big storm
about the middle

mean length: 13.25 letters

APPENDIX G: Brief Description of a Sixth, Unsucessful Study

A study was performed which bore not on the issue of word recognition directly, but on one of the assumptions and mechanisms presumed to underly all of the studies reported above. Following Sperling (1963, 1967) it has been assumed throughout that the mask terminates visual processing of the stimulus, though higher-order cognitive processes, presumed to be auditory or linguistic in nature, continue after iconic memory ceases. In many experiments, this abstract statement translates into a simple concrete process: the subject names letters or words to himself in order to retain them after their visual image has faded. It has further been assumed that the auditory processing mode is time-consuming. At the faster display speed used in the preceding experiments, the subject does not have time to identify all the letters of a word separately. Therefore, the subject attempts to "chunk" letters, to group them and to name the groups, rather than naming individual letters. When the stimulus strings are words, this chunking strategy is easy and effective -- so long as visual conditions permit it to occur. When the strings are random, chunking is more difficult and less effective; hence removing the mask greatly enhances word-recognition, while it hardly helps identification of random strings.

There is one straightforward implication of this assumption that relatively slow "auditory" processes take place after the icon has been eradicated by the mask: it should be the case that post-mask processing

APPENDIX G - CONTINUED

affects letter recognition, as pre-mask processing time time is known to do (Sperling, 1963).

An experiment was designed in which post-mask time was to be controlled by the simple expedient of presenting the subject with a new letter to recognize. Target letters or groups of letters were presented for 50 msec and followed by a mask. Then, after a delay varying from zero to 300 msec an additional letter was to be presented. Subjects were to be asked to identify all letters, but their accuracy scored for the initial letters only where they had correctly identified the final letter. (If subjects had not correctly identified the final letter, there would be no basis for assuming that they had actually shifted their attention to the new task.) Recognition accuracy was to be plotted as a function of the number of letters in the initial cluster, and of the time delay between the mask and the interference letter. The procedure was intended to answer two straightforward experimental questions: (1) would accuracy increase with post-mask processing time as the auditory encoding notion suggests? (2) would the amount of post-mask processing time needed to achieve a given average level of accuracy increase with the number of letters in the target group, as it should if encoding is a serial process?

This experiment was run in several versions with a large number of subjects. The results are not reported here because a crucial programming error was discovered in the process of writing this report. Misunderstanding the point of the study, the research assistant who programmed all displays had varied the interval between the target

APPENDIX G - CONTINUED

letter cluster and the mask, rather than between the mask and the interference letter, as the design required. Thus in effect he performed a series of studies on the effects of pre-mask processing time -- effects which have been abundantly documented.