CHAPTER 7

EXPERIMENT 4: THE DEPENDENCE OF WORD DISCRIMINATION ON THE NUMBER OF ALTERNATIVE COMPARATOR WORDS AND ON THE KNOWLEDGE OF THE VARIANT WORDS

7.1 Introduction

This experiment continues the attempt to determine how general the effect of prior experience on the stimulus component is likely to be. Again the interest centers on the nature of the prior experience. Two aspects were studied: the number of alternative comparator words, and the knowledge of the variant words.

7.1.1 The number of alternative comparator words

The prior experience given in experiments 2 and 3 prepared the subject for a single comparator word. There are some experimental and everyday situations in which the subject is prepared for a single word, but there are many more in which he is prepared for one of a number of alternatives. In view of this it is important to know whether or not the effect of prior experience on the stimulus component depends upon the subject being prepared for a single comparator word.

Performance of many kinds has of course been shown to vary with the number of alternative stimuli. For word recognition such an effect was shown by Postman and Bruner (1949). They found that recognition thresholds were higher when subjects were told that the displayed word would be either a colour name or a food name, than when they were told it would be a colour name. However, a similar experiment by Freeman and Engler (1955) failed to show any difference between these dual and single sets. Brown and Skinner (1964) provide evidence that these different outcomes were due to Postman and Bruner displaying two words on each trial and Freeman and Engler only one. In the present experiment only one word per display was used. Independence between performance and the number of alternatives may therefore be expected on the basis of Brown and Skinner's finding. This expectation cannot be strong, however, as the separation of stimulus and supplementary components may well show effects that were previously concealed.

7.1.2 Knowledge of the variant words

The relevance of this aspect of prior experience to the problem of generality was noted in the introduction to experiment 3. As the results of that experiment were equivocal, it is important to know whether knowledge of the variant words is essential to the effect of prior experience on the stimulus component when the comparator word is highly familiar.

In experiment 3 the stimulus component was found to decrease with an increase in the amount of prior experience of the comparator word, due to an increase in s (the probability of the subject saying 'Same' on 'different' trials). As already mentioned, this result suggests the occurrence of competitive processes, and is to some extent in keeping with the theories based on competition. These theories predict that the value of s will not decrease when greater amounts of prior experience are given, and may even increase.

7.2 Method

7.2.1 Outline

Word discrimination was studied under three conditions. In the first the subject was ready for a single highly familiar comparator word. In the second he was ready for any one of four highly familiar comparator words. In the third condition he knew only that the comparator word would be a CVCVCVC. In all three conditions the display sequence was exactly the same as in the LFD condition of experiment 2. The three conditions may best be designated by the number of alternative comparator words which were possible on each trial; that is, as the 1 condition, the 4 condition, and the 2×10^7 condition. The 1 condition was very similar to the HFD condition of experiment 2. The subject always knew which word was to be the comparator word, and all were highly familiar to him. This condition differs from the HFD condition in that the subject was given no prior experience of the variant words. The words displayed on 'different' trials were therefore words never seen before. In the 4 condition the comparator word on each trial was randomly selected from 4 different, highly familiar, words. The subject always knew what these 4 words were. Apart from the number of alternative comparator words possible, condition 4 was the same as condition 1. The 2 X 10^7 condition was the LFD condition of experiment 1 again. The comparator words were randomly selected from all possible CVCVCVC's, and none were familiar to the subject.

Twelve subjects were tested under each of these conditions. A single display duration was used for the target word; as in the last experiment this was 100 milliseconds.

7.2.2 Design

The experimental design was again a, 3 X 12, design. Serial and order effects were controlled as in the previous experiments, except that a balanced design within subjects was not used. In partial compensation for this, a longer practice period was given. Again, conditions were given in a counter-balanced order across subjects. Each possible order of the three conditions occurred for exactly two subjects.

7.2.3 Procedures and instructions

One session, lasting about 1½ hours, was required per subject. The sessions began with at least 15 minutes practice, in which the displayed words were selected as in the 2 X 10^7 condition.

The experimental trials for each condition were given in a single block, with 40 discriminations per condition. These were divided into four sets of 10 discriminations. Every set of 10 discriminations was preceded by four brief displays which, in the 1 and 4 conditions, reminded subjects of the comparator words to be prepared for. In the 1 condition a different comparator word was used for each set. In the 4 condition the same 4 words were used in each set, selection from these being random.

For each subject the comparator words used in the 1 condition were also those used in the 4 condition. A new set of words was used for each subject. Each subject was given his four comparator words at least a day before the experiment and requested to learn them. For the 2 X 10^7 condition 40 comparator words were required per subject, and for each subject a new set of 40 was used.

Instructions were given during the practice session according to the protocol given in Section 5.2.3, except that sections 5 and 6 were omitted and the following added:

> At the start of the 1 condition tell subject that one comparator word will be used in each set of 10 discriminations, and that the one to be used will be shown to him four times at the beginning of each set.
>
> At the start of the 4 condition tell subject that on every trial the comparator word will be randomly selected from the four he has learned, and that to remind him of this the four words will be shown once each at the beginning of each set.

At the start of the 2 X 10^7 condition tell subject that the comparator words will be randomly selected from all possible CVCVCVC's. Tell him that the word shown briefly four times at the beginning of each set is irrelevant to the experiment and is included only for control purposes.

7.2.4 Subjects

The subjects were 12 psychology undergraduates, acting as unpaid subjects in partial fulfilment of their course requirements. Their ages ranged from 18 to about 36 years. Six were male, and six were female. None had been used in previous experiments.

7.3 Results

The number of correct and incorrect responses for each subject and condition are given in Table 1 of Appendix 4. The separate totals for 'same' and 'different' trials are given in Tables 2 and 3 of Appendix 4. These results are analyzed in terms of letter discrimination performance and in terms of the proportions of correct responses.

7.3.1 Letter discrimination performance

The number of letters discriminated by each subject under each condition were calculated from the results given in Tables 2 and 3 of Appendix 4 and are given in Table 1.

TABLE 1: LETTER DISCRIMINATION PERFORMANCE

SUBJECT	NUMBER OF ALTERNATIVE COMPARATOR WORDS		
	2×10^7	4	1
1	2.9	5.4	4.8
2	0.0	6.0	6.5
3	5.3	3.9	6.2
4	2.9	6.2	5.2
5	4.3	6.1	6.6
6	0.3	0.0	2.6
7	5.0	6.0	5.4
8	1.6	3.2	4.0
9	6.5	4.7	6.2
10	3.4	5.7	6.6
11	4.5	5.5	3.5
12	4.1	4.9	6.2
MEANS	3.4	4.8	5.3

Again the use of a single display duration of 100 milliseconds (with pre-stimulus and post-stimulus noise fields) is seen to be reasonably satisfactory. No subject always saw all of the word, and no subject always saw none of the word.

To determine whether the differences in letter discrimination scores under the different conditions were significant an analysis of variance was performed. The results of this analysis are given in Table 2.

TABLE 2: SUMMARY OF ANALYSIS OF VARIANCE PERFORMED ON LETTER DISCRIMINATION SCORES

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	P
Prior knowledge	23.6	2	11.8	6.9	<.01
Subjects	61.2	11	5.6		
Prior knowledge X subjects	36.4	22	1.7		
Total	121.2	35			

The significance of the conditions effect justifies a more detailed analysis. The critical difference between any pair of means required for significance at the .05 level on a two way t-test is 1.1. Comparison of the means of Table 1 on the basis of this value shows that performance under both the 4 and 1 conditions was superior to that under the 2×10^7 condition. Letter discrimination performance is thus raised by prior experience of the comparator words alone. Readiness for a single comparator word is also seen to be unnecessary. When the subject was prepared for any one of four comparator words his performance was still significantly raised by prior knowledge of those words. It is also important to determine whether performance is worsened if the subject is prepared for four comparator words rather than just one. On this test the difference between the 1 and 4 conditions does not approach significance. However, a further examination of this question will be reported in the next section.

Is the increased performance more likely to be due to changes in duration-sensitive or in duration-insensitive performance? An indication is given by the means of Table 3. These means are again produced by dividing the 12 subjects into two groups: all those scoring above the mean on the 2×10^7 condition, and all those scoring below the mean. Table 3 gives the means for those two groups under each condition.

TABLE 3: MEAN LETTER DISCRIMINATION PERFORMANCE

	NUMBER OF ALTERNATIVE COMPARATOR WORDS		
	2×10^7	4	1
Subjects scoring above mean on 2.10^7 condition	5.0	5.2	5.7
Subjects scoring below mean on 2.10^7 condition	1.9	4.4	5.0

These results indicate that knowledge of the comparator words improves the performance of subjects discriminating 2 letters on the 2×10^7 condition more than that of subjects discriminating 5 letters on the 2×10^7 condition.

7.3.2 Numbers and Proportions of correct and incorrect responses

Table 4 shows the numbers of correct and incorrect responses, summed over all subjects, for each condition. The proportions of correct responses are given in Table 5, together with the probability that the difference between individual pairs of means would occur by chance (estimated by the Normal approximation to the Binomial distribution). The dangers in making inference from multiple comparisons are assumed to be mitigated by the small probabilities obtained, and by the analysis of variance performed on the letter discrimination scores.

TABLE 4: NUMBERS OF CORRECT AND INCORRECT RESPONSES

	NUMBERS OF ALTERNATIVE COMPARATOR WORDS					
	2 X 10^7		4		1	
	Correct	In-correct	Correct	In-correct	Correct	In-correct
'Different' trials	144	76	160	54	180	50
'Same' trials	147	65	203	37	206	20
Total	291	141	363	91	386	70

TABLE 5: PROPORTIONS OF CORRECT RESPONSES

	NUMBERS OF ALTERNATIVE COMPARATOR WORDS		
	2 X 10^7	4	1
'Different' trials	.655	.748	.783
	←(< .05)→ (2 X 10^7 – 4)		
		←(> .3)→ (4 – 1)	
	←(< .01)→ (2 X 10^7 – 1)		
'Same' trials	.693	.846	.912
	←(< .01)→ (2 X 10^7 – 4)		
		←(< .05)→ (4 – 1)	
	←($\ll$ .01)→ (2 X 10^7 – 1)		

With respect to the comparison between the 2 X 10^7 condition and the other two conditions these results are in keeping with the conclusions drawn from the analysis of variance. These tests make more efficient use of the data, however, and unlike the analysis of variance they indicate a difference between the 4 and 1 conditions. The significant difference between the values of q under these two conditions indicates a difference in letter discrimination, and not simply a change in guessing strategy. If the difference in the values of q were due to a difference in guessing rates, the probability of a correct response on 'different' trials would be less under the 1 than under the 4 condition. It can be seen from Table 5 that this was not the case.

7.3.3 Some comparisons between experiments 3 and 4

Experiments 3 and 4 were performed under very similar conditions. The procedural differences that there were, such as the slightly greater number of discriminations in experiment 3, and the differences in the form of control for serial effects, are unlikely to account for the observed differences in performance. Comparison between the experiments therefore seems reasonable. The question of interest is whether the greater amount of experience of the comparator word in experiment 4 produced any greater increase in performance than the few seconds of experience in experiment 3. The relevant comparison is between the 1 second condition of experiment 3 and condition 1 of experiment 4. The proportion of correct responses on 'different' trials after much learning is significantly greater than the proportion after 1 second prior experience ($P < .01$). The proportion on 'same' trials is significantly greater at the .05 level. That this difference is performance is not due to subject and procedural difference, can be seen by comparing the conditions of no prior experience in the two experiments; that is, condition 0 of experiment 3 and condition 2 X 10^7 of experiment 4. The differences in the proportions of correct response between these two conditions are small and do not approach significance. Letter discrimination performance was therefore better when the comparator word was highly familiar than when it was seen for either 1 or 11 seconds.

7.4 Discussion

A rough estimate of the generality of stimulus component facilitation is now possible. The effect of prior experience on the stimulus component does not depend upon the subject being prepared for only one comparator word. It still occurs when the subject must be ready to discriminate the display against any one of a number of possibilities. In addition the effect does not require that the variant words be known. Situations in which the subject is prepared for one of a few highly familiar words are relatively common. In normal reading, for instance, most words are highly familiar, and both context and peripheral vision often limit the number of possible words. Such situations also arise in experimental work. Consider, for instance, experiments studying the effect of built-in rehearsal frequency on thresholds, such as that of Solomon and Postman (1952) or experiment 1. In these experiments some words become highly familiar, and partial information from pre-recognition presentations, together with the rehearsal itself, will often limit the number of possible words. It is therefore reasonable to suppose that in a substantial number of situations the stimulus component of word recognition will depend upon prior experience. No more precise statement of the degree of generality is possible because only a few values of learning duration and number of alternative words have been studied.

In addition to the implications with respect to generality a few other points emerge from experiments 3 and 4. These will be discussed in the remainder of this chapter.

Experiments 3 and 4 indicate that there may be a range of exposure durations over which prior experience has little or no effect on the stimulus component, and that large effects may occur only with large amounts of prior experience. These indications suggest a type of functioning which is not unreasonable in view of the large proportion of stimuli that are met only once or twice during a person's lifetime. It would be of little use to process the input in terms of whether it was or was not one of these. Recoding early in the transmission sequence will only be useful if performed in terms of stimuli that occur frequently. What amount is actually required before such recoding occurs would be shown by a more extensive study of the dependence of the stimulus component on the amount of prior experience.

The dependence of the stimulus component on the number of alternative comparator words is a most important result, because it provides a possible mechanism for the effects of context and other variables of 'perceptual set'. It is most likely that these variables, on some occasions, alter the number of alternatives for which the subject sets himself. If this is the case, then they also alter the stimulus component. The results of experiment 4 therefore provide evidence that at least some of the many known effects of such variables involve changes in the stimulus component.

The mechanism of the effect of number of alternatives is unknown. It might involve effects on read-out processes, or effects on read-in processes (i.e. the transformation of the input into the form in which it is read-out). No techniques capable of settling this issue are at present available. One experiment which is possible, however, is that of determining how long it takes for the input processing systems to get into the state of readiness for a single word. That some length of time is required is demonstrated by the difference in performance between conditions 1 and 4. A brief display could warn subjects of the relevant comparator word shortly before presentation of the target word. By varying the interval between the warning and target displays the required warning time could be determined.

The prediction of competition theories that, with no knowledge of the variant words, the probability s is greater for highly familiar than for unfamiliar words was clearly not confirmed. The probability s was instead much smaller for highly familiar words.

The final point is that prior experience affects the stimulus component even when the variant words are unknown. It appears, therefore, that both difference and identity relations between input and familiar words are computed and used in the processing of the input. Whether the identity of the difference is computed, or only the fact of difference, cannot be known from this experiment.

CHAPTER 8

THE WHOLE-WORD THEORY AND THE LETTER POSITION EFFECT

Experiments 3 and 4 have shown that the effect of prior experience on the stimulus component of word recognition is likely to be of considerable generality. Attention now returns to the mechanism of this effect. From the results of experiment 2 it was concluded that prior experience of the displayed words affects the stimulus component by allowing the input to be classified as a particular word prior to read-out. With all relevant aspects of the input thus given in a single classification limitations in the read-out and storage systems are avoided. If prior experience does modify input processing in this way, then all the other behavioural phenomena that result from the read-out and storage of a number of separate classifications will be affected by prior experience. A test of this prediction, for some phenomena at least, is an important step in the confirmation and development of the theory.

The best documented phenomenon believed to result from the read-out of a number of separate classifications is the letter position effect. The letter position effect is the relationship between the relative position of letters in a word and the proportion of trials on which they are correctly recognized. The whole-word theory predicts that this effect will depend upon word familiarity. However, no such dependence has as yet been reported. Fortunately, the prediction can be tested using the data of experiment 2. Although this experiment was not designed for such a purpose, it provides data that can be re-analyzed to show the relation between letter position and performance. This chapter therefore reviews the research on the letter position effect and gives the reasons for believing it to result from read out of a number of separate classifications. It then re-analyzes the results of experiment 2 to see if the relation between letter position and performance depends upon word familiarity. Finally it discusses the implications of the results for the whole-word theory, and for current explanations of the letter position effect.

8.1 A review of research on the effects of letter position

The relation between letter position and recognition accuracy has been discovered and forgotten at least twice. Pillsbury (1897), reporting a very extensive study of the recognition of misprinted words, noted a marked decrease in recognition accuracy proceeding from the first letter to the last throughout the word. This, he suggested, indicated a general tendency for the subject to read through the word from left to right, thus giving the first letters a more prominent part in the recognition of the word as a whole.

A few years later, workers in the German laboratories discovered that accuracy tended to rise again for the last one or two letters, producing an asymmetrical bow-shaped relation. Their results were reported by Woodworth (1938), who explained them in terms of mutual masking effects. He supposed that letters close together would come to overlap at some stage in the visual receptor systems, thereby reducing legibility; end letters, being overlapped only from one side, would suffer less masking, and would therefore be better recognized. He gives convincing demonstrations of such mutual masking effects. Resolution deficiencies of a similar kind have been suggested recently by Averbach and Coriell (1961). The implications of these notions seem not to have been explored, but they are of great interest as no transformations maintaining the topological relations of the stimulus display could achieve such masking.

In 1927 Crosland, using centrally fixated nonsense words, re-discovered the phenomenon. An examination of the dependence of the letter position effect on word length gave him the results shown in Figure 1. Crosland offered no explanation of his results, but Anderson and Dearborn suggested that:

> Crosland's results may be related to the direction of the English language. Learning to read, write, and spell are all accomplished from left to right in English. Left-to-right eye movements were not a factor in Crosland's experiments, in as much as the fixation point was controlled at the centre of the word, and 100 ms. of exposure time does not permit a change of fixation. Crosland's result may be said rather to express a left-to-right mindedness, which the practice of left-to-right eye movements serves to bring about. (Anderson and Dearborn, 1952, p.225-227).

A different line of thinking was begun by Mishkin and Forgays (1952) who, apparently unaware of the earlier work, discovered a new positional effect. Their study had its origins in Hebb's debate with the Gestalt theorists over the problem of stimulus equivalence. Its aim was to show that 'reading does not train all parts of the retina in the same way, even when acuity does not enter the picture' (Hebb, 1949, p.49). They displayed English words of eight letters either wholly to the left, or wholly to the right, of fixation. Recognition accuracy was found to be substantially higher for the words shown to the right of fixation. To demonstrate the dependence of this effect on the directional characteristics of the language they used the fact that Yiddish (if in Hebrew script) is written from right to left. Subjects familiar with both languages were shown English and Yiddish words in random order, and, as before, either to the left or right of fixation. Right field superiority occurred only for the English words. Recognition scores for the Yiddish words were higher in the left field than in the right, but not significantly. The conclusions drawn by Mishkin and Forgays were that:

> The results support the hypothesis that reading trains limited regions of the left hemiretina selectively. They are inconsistent with the theory of a general equipotentiality in vision since the learning involved in word recognition is not subject to complete transfer. Since there is an indication that English and Yiddish words are more accurately perceived in different visual fields, it appears that a more effective neural organization is developed in the corresponding cerebral hemispheres (left for English, right for Yiddish) as a result of training processes that are specific to the reading of those languages. It is suggested that a factor in the training may be the neural equivalent of a selective visual attention, although the data have indicated that when learning is complete this factor may no longer be operative. (Mishkin and Forgays, 1952, p.47).

The relationship of hemifield superiority to language training was further investigated by Orbach and by Forgays. Orbach (1952) showed that left field superiority for Yiddish words could be obtained, but only if this was the first learned language. Forgays (1953) showed that right field superiority in English speaking children does not normally develop until they reach Grade VII.

The contradiction between the classical work on the effects of letter position and the conclusions regarding lateral dominance went unnoticed, until pointed out by Heron (1957). He showed that when letters are exposed in left <u>and</u> right fields simultaneously more are recognized in the left field; but that when letters are exposed in the left field <u>or</u> the right field more are recognized in the right field. He showed also that when non-alphabetical material is used there is no difference between recognition scores in the right and left fields. These phenomena cannot be due to the selective training of limited retinal regions (nor can they be due to mutual masking effects). Heron therefore proposed, in effect, that the selective visual attention derived from eye movements has its effect, not through the selective training of retinal regions, but through a post-exposure process. Heron's explanation clearly relates the letter position effect to read-out and is therefore quoted at length. He says:

> It is obvious that the neural activity involved in perception must persist for some time after the stimulus has been presented. During this period it would be possible for the 'post-exposure' attentional process to operate.
>
> The most noticeable feature of this process, as the S's report and their objective results

> indicate, is that the exposed letters are attended to in the order that they would normally be read: letters which would tend to be fixated first under normal reading conditions have their traces 'scanned' first. Thus, there appears to be a close relationship between the eye-movements, or tendencies towards them, established by reading and the post-exposure process.
>
> If tendencies toward eye-movements are important in determining how the post-exposural process operates it is possible to see how the apparently contradictory results obtained under conditions of successive and simultaneous presentation can be reconciled. We know that in reading English there are two main types of eye-movement. The first is a series of short movements from left to right along the line of print, the second consists of movements from right to left at the end of each line. Thus the fluent English reader presumably has two tendencies established; faced with a line of print there is one tendency to fixate near the beginning of the line and another to move the eyes along it from left to right.
>
> When alphabetical material is exposed in the right field alone, the two tendencies would be acting together. When, however, it is exposed in the left field alone, the tendency to move the eyes to the beginning of the line (presumably the dominant one) would be in conflict with the tendency to move the eyes from left to right. Under conditions of successive presentation we should therefore expect that more letters would be recognized in the right field. When exposure occurs simultaneously in both fields, on the other hand, the dominant tendency to move the eyes to the beginning of the line would result in more letters being recognized in the left field. (Heron, 1957, p.46-47).

Heron's resolution of the contradiction has received wide acceptance and experimental confirmation (Terrace, 1959; Harcum and Jones, 1962; Harcum and Filion, 1963; Winnick and Dornbush, 1965). The experiments of Harcum and his colleagues show that letter position effects vary in accordance with the directional attributes of the stimuli. In one experiment, English words and mirror images of English words were presented to the left or to the right in random order (Harcum and Finkel, 1963). For the normal words, accuracy was higher when they were presented in the right field; but for the mirror images accuracy was higher when they were presented in the left field. From such results Harcum concluded that the scan sequence is controlled by an earlier discrimination of the specific characteristics of the stimulus after the exposure has been initiated. This conclusion is in accord with the view that the input is classified as a particular word prior to read-out.

Recently, Kimura (1961) has suggested that there might be a left-right difference in tachistoscopic word recognition as a result of the cerebral dominance associated with speech representation.[1] Bryden (1965) pointed out that such an effect might occur but be largely obscured by the positional effects deriving from learned reading habits. To remove the obscuring effects Bryden displayed single letters only, and Barton, Goodglass, and Shai (1965) displayed vertically printed words. The results of both experiments suggest that there may be a slightly higher recognition accuracy for non-directional verbal material arriving in the dominant hemisphere.

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1 This suggestion is not related to the lateral dominance proposed by Mishkin and Forgays; it predicts a left field superiority for most subjects, irrespective of the directional characteristics of the language.

Although Heron's interpretation of the letter position effect is widely accepted there are some problems that it does not resolve. First, it is not clear why the position of a letter in the scan sequence should be related to recognition accuracy. Is it because the scan sometimes fails to reach the later letters, or is it because the later letters, although scanned, are more likely to be lost in storage? Harcum and Jones (1962) choose the latter alternative but do not say why. Second, no reasons are offered for supposing that the scanning order is derived from eye movements rather than from the order required for visual-acoustic correspondence. In English, the visual-acoustic correspondence is such that the initial sounds of a word correspond to the left parts of the printed word. It is therefore only by learning to process the printed word from left to right that this correspondence can be utilized. There is no obvious reason why such left-to-right processing must be associated with left-to-right saccadic eye movements. In view of the weight of evidence involving the acoustic system in tachistoscopic word recognition, the scanning order seems just as likely to derive from the normal requirements for visual-acoustic correspondence as from eye movements. Third, a recent experiment by Bower (1965) throws doubt on the notion that read-out involves a scanner constrained to move across the display in an orderly fashion. Bower's experiment showed that subjects, if given a great deal of practice, can be trained to attend to the different letter positions in <u>any</u> order without loss of efficiency. He suggests that read-out involves not a scanner but a large number of filters, which can open in any order dictated by environmental contingencies, and which feed into a funnel (i.e. which can open only one at a time). Bower's finding can perhaps be reconciled with scanning theories by noting that environmental contingencies would normally require the filters to open in an orderly fashion from left to right. Lastly, another recent experiment provides evidence that read-out is not constrained to take one item at a time, but can, to a limited extent at least, take a number of items simultaneously (Weisstein, 1966).

Notwithstanding these difficulties the conclusion that letter position effects are related to read-out appears sound. It seems most likely that the letter position effects originate, in large part, at or after read-out. There may be in addition a small effect due to cerebral dominance, favouring, for most subjects, letters in the right hemi-field, and originating, presumably, prior to read-out.

If the above conclusions and the whole-word theory are correct, then the letter position effect will largely disappear under conditions of whole-word processing; for read-out of the displayed word as a single unit will remove those differences between letters that originate at or after read-out, and leave only whatever differences originate earlier.

8.2 Re-analysis of the data of experiment 2

The conclusion that familiar words are read out as single units was drawn from the superiority of the HFD over LFD and LFI performance at the three shortest durations of exposure (i.e. 50, 55, and 60 milliseconds). The prediction drawn from this conclusion was therefore tested by examining performance at these durations.

Performances at the three durations were combined and the values of z for each letter position and subject were calculated. For the HFD and LFD conditions this calculation required, for each position, the proportion of trials on which the subject said 'Same' when a change occurred at that position. These proportions for both conditions, and for each subject separately, are given in Tables 1 and 2, Appendix 5. The values of z were calculated from these proportions by equation 14 (Chapter 3), which in this case becomes:

$$E(z_i) = 1\left(1 - \frac{s_i}{q}\right)$$

where $E(z_i)$ is the z score for the ith position, and s_i is the probability that the subject says 'Same' when a change occurs at that position. It is assumed that q takes the same value for all letter positions. In other words, it is assumed that the probability that the subject says 'Different' when no difference is detected is independent of the position of any undected difference. There seems to be no reason to doubt this assumption.

To calculate the values of z for each position in the LFI condition it is necessary to use the position score Sp. The values of z were calculated according to equation 5 (Chapter 3), which in this case becomes:

$$E(z_i)_C = \frac{20\ E\ (Sp_i) - 1}{19}$$

for consonants; and

$$E(z_i)_V = \frac{5\ E\ (Sp_i) - 1}{4}$$

for vowels. $E(z_i)$ is the z score for the ith position, and $E(Sp_i)$ is estimated by the average value of Sp for the ith position. The average values of Sp for each position were obtained from Table 4, Appendix 2, by taking the average value for each subject over the durations 50, 55, and 60 milliseconds.

The values of z thus obtained for the LFD, LFI, and HFD conditions are given in Tables 1, 2 and 3, together with the mean values over all subjects.

TABLE 1: THE VALUE OF Z FOR THE LFD CONDITION FOR EACH SUBJECT AND LETTER POSITION

SUBJECT	LETTER POSITION						
	1	2	3	4	5	6	7
1. (R.M.K.)	.70	.50	.62	.17	.16	.00	.33
2. (M.G.)	1.00	1.00	.81	.04	.28	.14	.07
3. (A.J.P.)	.84	.71	.30	.40	.28	.00	.12
4. (A.S.)	.53	.34	.14	.00	.04	.17	.00
5. (E.P.)	.68	.36	.28	.00	.00	.16	.12
6. (T.V.)	.34	.55	.25	.12	.37	.00	.02
MEAN	.68	.57	.40	.12	.19	.08	.11

TABLE 2: THE VALUES OF Z FOR THE LFI CONDITION, FOR EACH SUBJECT AND LETTER POSITION

SUBJECT	LETTER POSITION						
	1	2	3	4	5	6	7
1. (R.M.K.)	.60	.51	.38	.31	.16	.19	.18
2. (M.G.)	.80	.75	.50	.28	.29	.13	.25
3. (A.J.P.)	.79	.77	.49	.39	.21	.30	.39
4. (A.S.)	.40	.45	.32	.20	.15	.11	.09
5. (E.P.)	.75	.49	.23	.24	.20	.16	.35
6. (T.V.)	.33	.35	.24	.26	.15	.14	.03
MEAN	.61	.55	.36	.28	.19	.17	.22

TABLE 3: THE VALUES OF Z FOR THE HFD CONDITION, FOR EACH SUBJECT AND LETTER POSITION

SUBJECT	LETTER POSITION						
	1	2	3	4	5	6	7
1. (R.M.K.)	.91	.48	.59	.70	.77	.68	.57
2. (M.G.)	.83	.95	.93	.78	.82	.55	.50
3. (A.J.P.)	.95	.90	.09	.91	.74	.88	.78
4. (A.S.)	.45	.75	.63	.61	.14	.26	.30
5. (E.P.)	.73	.09	.72	.30	.35	.23	.57
6. (T.V.)	.30	.12	.59	.67	.36	.94	.57
MEAN	.70	.55	.59	.66	.53	.59	.55

These values of z are estimates of the probabilities that letters in each position are discriminated or identified, where all probabilities are corrected for guessing. The mean values of z over all subjects are plotted in Figure 2. It can be seen that recognition performance at letter positions 1 and 2 is very similar under all three conditions. It is with respect to recognition of the letters in the remaining positions that the conditions differ.

Table 4 summarizes an analysis of variance performed on the z scores.

TABLE 4: SUMMARY OF ANALYSIS OF VARIANCE PERFORMED ON Z SCORES

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	P
Condition(C)	2.0726	2	1.0363	49	<.01
Position(P)	2.3959	6	.3993	8.4	<.01
Subject(S)	1.4204	5	.2840		
C X P	1.0427	12	.0869	3.71	<.01
S X C	.2100	10	.0210	.90	NS
S X P	1.4217	30	.0473	2.0	<.05
S X C X P	1.4069	60	.0234		
TOTAL	9.9702	125			

As expected, both condition and letter position effects are highly significant. It is apparent from Figure 2 that the position effect obtained under high familiarity conditions differs from that obtained under low familiarity conditions. The analysis of variance shows that this interaction between condition and position is highly significant. It can also be seen from Table 4 that the effect of conditions does not vary significantly across subjects, but that the effect of position does.

Performance at the three shortest durations was combined because there were insufficient observations in the HFD and LFD conditions to allow examination of the letter position effect at each duration separately. It might be argued, however, that combining performance in this manner could give a distorted picture of the effect of letter position. As the LFI condition provides a sufficient number of observations, the interaction of the letter position effect with display duration was examined for this condition. The mean z scores over all subjects for each duration and letter position were calculated from the results given in Table 4, Appendix 2. These scores are given in Table 5 and are plotted in Figure 3.

TABLE 5: THE VALUE OF Z FOR EACH LETTER POSITION AND DISPLAY DURATION. LFI CONDITION, AVERAGED OVER ALL SUBJECTS

DISPLAY DURATION	LETTER POSITION						
	1	2	3	4	5	6	7
200	.97	.93	.82	.77	.68	.54	.70
90	.88	.83	.64	.55	.43	.40	.45
70	.82	.74	.53	.46	.33	.25	.35
60	.72	.65	.42	.32	.29	.17	.30
55	.62	.59	.40	.33	.16	.21	.21
50	.50	.43	.25	.22	.14	.14	.15

It is clear from Figure 3 that over the range of durations studied there is no substantial interaction between the letter position effect and display duration. This is a result of great interest which will be discussed in more detail in Section 8.3.2.

In summary, the main findings regarding the letter position effect are as follows:

1. There were large effects of letter position in the LFD and LFI conditions. These effects were very similar under the two conditions, and similar to those reported by Crosland (see Figure 1).

2. There was little or no effect of letter position in the HFD condition.

3. Recognition of the letters in positions 1 and 2 was no better for familiar than for unfamiliar words.

4. The effect of letter position in the LFI condition was largely independent of display duration.

8.3 Discussion

These results carry important implications for the whole-word theory, and for contemporary theories regarding read-out and the letter position effect. These implications will be discussed in turn.

8.3.1 The whole-word theory

The prediction derived from the whole-word theory was clearly confirmed. The letter position effect was not only reduced but very largely removed by prior experience of the displayed words. As the absence of a letter position effect in word recognition has not before been either reported or predicted and was *a priori* unlikely, this result provides strong support for the whole-word theory.

Interesting implications arise regarding the origins of information loss in the HFD condition. Information is unlikely to be lost during or after read-out if only a single classification is read out. Performance in the HFD condition may therefore be assumed to show what information loss occurs in the receptor systems. It can be seen from Figure 2 that at letter positions 1 and 2 performance under LFD and LFI conditions differs little from that under HFD conditions. This suggests that, under low familiarity conditions also, all information loss at positions 1 and 2 occurs in the receptor systems. It further suggests that information loss at the remaining positions under low familiarity conditions is divided into two parts: loss occurring prior to read-out (shown by performance on the HFD condition); and loss occurring at or after read-out (shown by the difference in performance under high and low familiarity conditions).

The extent to which performance was independent of letter position in the HFD condition indicates that the processes classifying the input as a particular word operate on all letters simultaneously. The relation between simultaneous or successive processing of the letters and classification of the input as a whole word can now be clarified. Classification of the input as a single word simply requires that a single classification, and hence a single signal, can specify the whole of the relevant input. It does not require that the processes classifying the input as a particular word operate on all letters simultaneously. The relation between performance and letter position in the HFD condition suggests that this processing is concurrent nevertheless.

The effect of prior experience on word recognition can now be explained as being due (in part) to the removal of the letter position effect by classification of the input as a single whole word prior to read-out. If this explanation is correct further understanding of the role of prior experience in the word recognition process will result from a better understanding of read-out and the letter position effect. It is with these that the next section is concerned.

8.3.2 Read-out and the letter position effect

The view that the letter position effect is associated with read-out gains further support from the present results. Firstly, the disappearance of the effect in the HFD condition is further evidence that the effect is not due to limitations in relatively peripheral input processes (e.g. resolution limitations, or mutual masking). If the effect was due to limitations operating prior to the classification of the input as a particular word it would be reasonable to assume that it would be observed with both familiar and unfamiliar words. Secondly, the similarity of the letter position effect in the LFI and LFD conditions shows that the effect is not due to the processes of reproduction. In word identification tasks reproduction is always sequential, and usually from left to right. The possibility that this might account for the letter position effect is a difficulty that has frequently been noted (e.g. Crosland, 1931; Harcum and Finkel, 1963). This difficulty is clearly removed by the occurrence of the letter position effect in the LFD condition, because in this condition no order of reproduction is involved.

Not all aspects of Heron's explanation of the letter position effect are confirmed by the present results. The first aspect on which doubt is thrown is the view that the effect arises from a <u>post-exposure</u> process which scans a persisting image (Heron, 1957; Terrace, 1959; Harcum and Jones, 1962). The present results show that the letter position effect occurs even though the display is very brief and immediately followed by a noise field. Any theory claiming that scanning is across a persisting image must, therefore, explain why this image is not masked by the immediately following noise field. Heron's explanation does not do this. One that does will be suggested later.

Another aspect of Heron's explanation that requires revision is the view that the letter position effect results from the eye-movements involved in reading verbal material. This explanation predicts that the letter position effect will increase with word familiarity, or at least be independent of it. It certainly does not predict that the effect will be greater for unfamiliar words.

The most interesting problem is that raised by the independence of the letter position effect and the duration for which the display is available. Assume that read-out does involve a process scanning across a visual display, and consider the effect of erasing this display, after various durations, by a noise field. As the display duration decreases there will come a time, dependent on the scan rate, when the display will be erased just before the scanning process reaches the last letters. At this duration recognition of the letters scanned last would deteriorate, but reproduction of the letters scanned first would be unaffected. Decreases in display duration would, therefore, accentuate the effect of letter position by further reducing the probability of successful transmission of the letters scanned last. It can be seen from Figure 3 that this was not the effect observed; decreases in display duration affected all letter positions approximately equally.

It might appear that this result could be explained by assuming that the scan rate is such that the whole word is covered in less than 50 milliseconds. If this were the case, however, an increase in exposure duration beyond 50 milliseconds would not improve performance, which it did. What the results indicate, therefore, is that decreases in display duration affect recognition accuracy but do not interrupt any scanning or sequential process. This seems to imply that if there is a scanning process (and the regular decrease in accuracy from left to right suggests that there is) then it must operate after the word has been presented as Heron suggests. This can only be the case, however, if the display scanned is not erased by noise fields, and the erasing action of noise fields is well established (Averbach and Coriell, 1961; Sperling, 1963).

It is possible to resolve this paradox by distinguishing between general visual storage and erasure, and special visual storage and erasure. Assume that there is a hierarchical sequence of transformations in visual information processing such that at the lower levels the properties represented are relatively simple and general, such as lines, edges, and angles, and that at the higher levels the properties represented are more complex and particular, such as letter identity. For the lower levels such a sequence of transformations is of course well established (Hubel, 1963). If each level has its own storage properties, and if information at any level is erased only by new input to that level, it can be seen how the apparently paradoxical results could arise. The noise field used in experiment 2 would give rise to input to the lower levels only. It would erase any information stored at those levels, and thereby reduce the length of time available for the read-in of information to the level of letter identity. This would account for the effect of display duration on duration-sensitive performance. Any information already stored at the level of letter identity would not be erased by the noise fields, however, and scanning of the information stored at this level could therefore be post-exposural. Thus, in a system of this kind, it would be possible for noise fields to affect recognition accuracy even though they do not erase the display that is scanned. In relation to such a system the whole-word theory proposes that experience with words adds a further level, and that the experience of new words simply adds new units to that level. Further implications of this theory will be discussed in the following chapters.

CHAPTER 9

EXPERIMENT 5: THE RECOGNITION OF WORDS PRESENTED IN RAPID SUCCESSION

9.1 Introduction

The experiment reported in this chapter extends the investigation to conditions of higher input load. In all earlier experiments one seven-letter word was presented on each trial. In this experiment two seven-letter words were presented and performance was studied under both high and low familiarity conditions. Such an extension is important for two main reasons. First, every-day word recognition tasks usually involve the recognition of more than a single word. The present experiment therefore provides evidence relevant to the issue regarding the generality of stimulus component facilitation. Second, as the whole-word theory states that under high familiarity conditions words are read out as single units, it predicts that storage limitations should not be met until at least three or four words are read out. But it was observed in experiment 2 that HFD performance levelled-off at about 6.5 letters. It was suggested in Section 5.4.3 that this might be a ceiling effect. The present experiment provides a test of this explanation by giving performance the opportunity to rise above seven letters as the whole-word theory predicts.

Each trial consisted of two brief displays, with one seven-letter word in the first display and another in the second display. Subjects attempted to reproduce both words. Between the two displays there was a brief interval during which the noise field was shown. This interval will be called the _inter-stimulus interval_, or ISI. Four different ISI durations were used. A display sequence of this kind was chosen for three reasons:

1. Problems of resolution and peripheral acuity are likely to arise if a large number of letters are shown in a single display; the display will either be such that the letters are small and crowded together, or such that many letters are seen peripherally.

2. The continuous extraction of information from displays that rapidly succeed one another is the task that is most common outside of the psychological laboratory.

3. A prediction derived from the theory of special storage and erasure can be tested by a study of recognition when two word displays are separated by an interval during which a noise field is shown. This prediction is derived in the next paragraph.

The theory of special storage and erasure outlined in Section 8.3.2 proposes that the persisting image of a display that contains letters will be more effectively erased by a display that also contains letters than by a display that does not contain letters. This theory predicts, therefore, that if two displays containing letters are separated by an interval in which a noise field is shown, performance will improve as the inter-stimulus interval is increased.

The theory of backward visual masking proposed by Averbach and Coriell (1961), however, leads to a different prediction. These authors suggest that there are two ways in which a later stimulus may interfere with a preceding one: 1) With a short interval between the stimuli the later stimulus is superposed over the stored image of the preceding stimulus; 2) With a longer interval between the stimuli in the later stimulus is substituted for the preceding stimulus. Averbach and Coriell proposed that both of these masking processes are highly dependent upon the retinal locations of the two stimuli: the later stimulus masks only those preceding stimuli that were projected onto the same retinal region. They do not propose, however, that these processes are dependent upon stimulus identity: any stimulus is superposed over, or substituted for, any other stimulus. A similar account is given by Sperling (1963). The noise field used in the present experiment was noise field 2 shown in Figure 4 of Chapter 4. It can be seen that if masking was due to superposition then this noise field would mask the preceding display at least as effectively, and probably more effectively, than would another word. If, on the other hand, masking was due to substitution it could be assumed that the masking effects of noise displays would be the same as those of word displays. The theory proposed by Averbach and Coriell, and by Sperling, predicts therefore that performance will either worsen as the inter-stimulus interval increases or will be independent of it.

9.2 Method

9.2.1 Outline

The experiment studied the recognition of two words presented in rapid succession, under both high and low familiarity conditions. For both conditions, the subjects were requested to reproduce as accurately as possible the two words displayed. (It would also have been of interest to use the word discrimination method but this requires the presentation of four words in fairly rapid succession. This is difficult with a three-channel tachistoscope).

In the low familiarity identification (LFI) condition the two words were selected randomly and independently from the 2×10^7 possible CVCVCVC's. In the high familiarity identification (HFI) condition, the method of random changes was used as there appears to be no other way of separating stimulus and supplementary components under such conditions. The same comparator word was used for both first and second words and the random changes were produced for first and second words independently.

Four different ISI durations were chosen on the basis of preliminary experiments: 0, 40, 100, and 300 milliseconds. A display duration of 100 milliseconds was used for the target words. The display sequences used were therefore as indicated in Figure 1. The word displayed first will be called word 1, and the word displayed second will be called word 2. The illumination of all three fields was 22 lumens/sq. ft. It was necessary to make all field illuminations equal because it is probable that the masking properties of fields varies with illumination. Trials were also included on which a single word was displayed for 100 milliseconds (single word trials). As usual this display was preceded and followed by noise fields. Performance under this condition provided a basis against which performance with two words could be compared.

9.2.2 Design

Four subjects were used, and each performed under all combinations of ISI durations and familiarity conditions. This required four experimental sessions per subject. Each session was divided into four phases and the conditions were distributed across these phases as shown in Tables 1 and 2.

Within each phase performance was studied under each of the four ISI's, and with a single word only. These five different tasks were performed within each phase in a randomly selected order, a new random

TABLE 1 THE ORDER IN WHICH CONDITIONS WERE GIVEN SUBJECTS 1 AND 3

SESSION	PHASE 1	2	3	4
1	LFI	HFI	HFI	LFI
2	HFI	LFI	LFI	HFI
3	HFI	LFI	LFI	HFI
4	LFI	HFI	HFI	LFI

TABLE 2 THE ORDER IN WHICH CONDITIONS WERE GIVEN SUBJECTS 2 AND 4

SESSION	PHASE 1	2	3	4
1	HFI	LFI	LFI	HFI
2	LFI	HFI	HFI	LFI
3	LFI	HFI	HFI	LFI
4	HFI	LFI	LFI	HFI

selection being made for each phase, session, and subject. Subjects were told which of the five tasks was to be performed next.

9.2.3 Procedure

The four subjects used were subjects 1, 2, 3 and 4 of Experiment 2. They were therefore well acquainted with the basic experimental situation. Nevertheless to familiarize them with the task of writing down two words, the first experimental session for each subject began with about 15 minutes practice. It was suggested that they write down as much of the first word as they could remember, then as much of the second as they could remember, and then go back and fill in any gaps. The manner in which the words were selected for the high and low familiarity conditions was explained to them. During the practice period the subjects performed under both conditions and at all four ISI's.

Under the LFI condition there were 15 trials within each phase; three at each ISI and three with a single word. This gave a total over all subjects of 96 trials at each ISI, and 96 trials with a single word, and required 240 randomly constructed CVCVCVC's. Each subject saw each word once. Under the HFI condition there were 35 trials in each phase: seven at each of the four ISI's and seven with a single word. This gave a total over all subjects of 224 trials at each ISI, and 224 trials with a single word. One comparator word was used per session per subject. With four sessions and four subjects this required 16 comparator words and their associated sets of variations. The subjects were familiarized with the comparator and variant words exactly as in experiment 2.

9.3 Results

For the HFI condition, over all four ISI's and over all four subjects, there were 866 reproductions of both words 1 and 2. Word 1 was correctly reproduced 552 times (i.e. on 64 per cent of trials), and word 2 was correctly reproduced 510 times (i.e. on 59 per cent of trials). For the LFI condition, over all four ISI's and over all four subjects, there were 384 reproductions of words 1 and 2. Word 1 was correctly reproduced 11 times (i.e. on three per cent of trials), and word 2 was never correctly reproduced. Any other direct comparison of HFI and LFI performance will show similarly large differences. To determine whether these differences result only from the different probabilities of being correct by chance under HFI and LFI conditions it is necessary to calculate the z score obtained under the two conditions.

The numbers of correct and incorrect responses for 'same' and 'different' trials separately in the HFI condition are given in Table 1, Appendix 6, for each subject and ISI. These numbers were obtained by scoring the subjects reproductions as in word discrimination experiments. Any variant word was taken as equivalent to the response 'Different', and the comparator word was taken as equivalent to the response 'Same'. The numbers of letters correctly reproduced, irrespective of position (Sc), in the LFI condition are given in Table 2, Appendix 6, for each subject and ISI. From the data in these two tables the z scores for the two conditions were calculated. As in experiment 2, equation 14 was used for the HFI condition, and the graphical solution of equation 8 for the LFI condition. The reproductions of words 1 and 2 were scored separately, and the resulting z scores are given in Tables 3 and 4 respectively.

TABLE 3 THE Z SCORES OBTAINED FOR WORD 1

		ISI (Milliseconds)			
	SUBJECT	0	40	100	300
LFI	1	1.6	2.5	4.2	4.2
	2	2.3	2.4	2.3	3.4
	3	2.0	3.6	4.6	5.1
	4	2.9	3.0	3.0	3.4
	MEANS	2.2	2.9	3.5	4.0
HFI	SUBJECT				
	1	4.3	4.0	6.2	6.5
	2	2.6	3.8	5.6	5.7
	3	6.0	5.5	5.4	6.7
	4	2.7	4.5	5.4	4.9
	MEANS	3.9	4.4	5.7	6.0

TABLE 4 THE Z SCORES OBTAINED FOR WORD 2

	SUBJECT	ISI (Milliseconds) 0	40	100	200
LFI	1	2.0	2.7	1.1	1.5
	2	1.3	1.9	1.0	1.3
	3	3.9	2.6	2.2	2.4
	4	1.3	2.1	1.6	2.5
	MEANS	2.1	2.3	1.5	1.9
HFI	SUBJECT				
	1	6.6	4.5	4.4	6.0
	2	4.8	5.4	3.1	5.6
	3	5.1	2.4	5.0	5.6
	4	3.3	4.2	2.5	3.8
	MEANS	5.0	4.1	3.8	5.3

The z scores were also calculated for those trials on which a single word only was presented and the scores are given in Table 5.

TABLE 5 THE Z SCORES OBTAINED FOR THE SINGLE WORD TRIALS

	LFI	HFI
SUBJECT		
1	5.0	6.6
2	5.0	6.7
3	5.8	6.7
4	4.5	4.7
MEANS	5.1	6.2

Figure 2 shows the z score for each condition and ISI, averaged over all subjects.

An analysis of variance was performed on the z scores for word 1 and is summarized in Table 6. The effect of both familiarity and ISI are highly significant, but none of the interactions approaches significance. A similar analysis performed on the z scores for word 2 is summarized in Table 7. The effect of familiarity is significant, but not that of ISI. None of the interactions is significant.

The numbers of correct and incorrect responses for word 2 of the HFI condition (scored as for word discrimination) are given in Table 8. A chi-square test of independence failed to show any relation between ISI and the probability of a correct response ($\chi^2 = 4.6$, degrees of freedom = 3; $P > .20$). Similar tests carried out for 'same' and 'different' trials separately also failed to show any significant relation between performance and ISI for word 2.

The relation between letter position and performance for the LFI condition is shown in Tables 9 and 10. These tables give, for each ISI and for each letter position, the z scores calculated from the mean value of Sp for that letter position. These results are presented in Figures 3 and 4 and will be discussed in the next section. Figures 3 and 4 also show the effect of letter position for those LFI trials on which a single word was shown.

TABLE 6 SUMMARY OF THE ANALYSIS OF VARIANCE PERFORMED ON THE Z SCORES - WORD 1

SOURCE OF VARIATION	SUM OF SQUARES	DEGREE OF FREEDOM	MEAN SQUARE	F	P
Familiarity (F)	26.46	1	26.46	82.69	$<.01$
Inter-Stimulus Interval (I)	18.70	3	6.23	23.07	$<.01$
Subjects (S)	8.27	3	2.91		
F X I	.41	3	.14	.18	NS
S X F	.96	3	.32	.42	NS
S X I	2.41	9	.27	.35	NS
F X I X S	6.97	9	.77		
TOTAL	64.63	31			

TABLE 7 SUMMARY OF THE ANALYSIS OF VARIANCE PERFORMED ON THE Z SCORES - WORD 2

SOURCE OF VARIATION	SUM OF SQUARES	DEGREE OF FREEDOM	MEAN SQUARE	F	P
Familiarity (F)	52.28	1	52.28	24.32	$<.05$
Inter-Stimulus Interval (I)	4.83	3	1.61	2.06	NS
Subjects (S)	5.34	3	1.78		
F X I	2.62	3	.87	1.45	NS
S X F	6.45	3	2.15	3.58	NS
S X I	6.98	9	.78	1.30	NS
F X I X S	5.36	9	.60		
TOTAL	83.86	31			

TABLE 8 THE NUMBER OF CORRECT AND INCORRECT RESPONSES FOR WORD 2 OF THE HFI CONDITION (SUMMED OVER ALL SUBJECTS)

	ISI (MILLISECONDS)			
	0	40	100	300
CORRECT	163	148	147	160
INCORRECT	56	66	71	55

TABLE 9 THE Z SCORES FOR EACH LETTER POSITION - LFI CONDITION, WORD 1

	LETTER POSITION						
ISI	1	2	3	4	5	6	7
0	.54	.49	.20	.15	.14	.18	.16
40	.83	.64	.40	.15	.16	.11	.20
100	.92	.79	.49	.31	.19	.19	.28
300	.91	.83	.63	.36	.21	.26	.33

TABLE 10 THE Z SCORES FOR EACH LETTER POSITION - LFI CONDITION, WORD 2

	LETTER POSITION						
ISI	1	2	3	4	5	6	7
0	.48	.36	.22	.08	.09	.09	.14
40	.72	.49	.27	.15	.11	.11	.11
100	.54	.38	.20	.00	.00	.13	.02
300	.59	.59	.26	.06	.05	.03	.05

In the preceding experiments performance under high familiarity conditions was studied in terms of the subject's ability to determine whether there was a difference between target and comparator words. In other words, the function studied was that of <u>difference detection.</u> The present experiment provides, in addition, evidence regarding the subject's ability to determine the nature of any difference between target and comparator words. Evidence regarding such <u>difference identification</u> was available because subjects attempted to reproduce the target word as accurately as possible on all trials.

For word 1, and over all subjects and ISI's, there were 464 'different' trials. The target word was correctly reproduced on 272, or .586, of these trials. For word 2, and over all subjects and ISI's, there were 427 'different' trials. The target word was correctly reproduced on 219, or .513, of these trials. Both of these values are far higher than could occur by chance if no differences were actually identified. Even if difference detection occurred on every trial, the proportion of correct reproductions in the absence of difference identification would be only 1/7, or .143. On the other hand both values are smaller than would be possible if difference identification occurred as frequently as difference detection. If it did, the probability of a correct reproduction on 'different' trials would be Ø (the probability of difference

detection), plus a small amount due to guessing.[1]
From equations 9 and 11, Section 3.5.3

$$\emptyset = \frac{u - p}{1 - p}$$

$$= 1 - \frac{s}{q} \qquad (15)$$

For word 1, and over all subjects and ISI's combined, Ø, calculated according to equation 15, was .714. With a population proportion of .714 the probability of obtaining only 272 correct reproductions out of 464 trials (i.e. a proportion of .586) is very small (the standardized normal variable $Z = 6.1$; $P \ll .001$). For word 2, over all subjects and ISI's the value calculated for Ø was .647. With a population proportion of .647 the probability of obtaining only 219 correct reproductions in 427 trials (i.e. a proportion of .513) is also very small ($Z = 5.8$; $P \ll .001$). In making these tests, estimates of Ø were used and sampling errors were not taken into account. These estimates were however based on very large samples. Furthermore, because Ø does not include the successes due to chance, it is an underestimate of the proportion of correct reproductions expected if difference detection and difference identification are equally frequent. It is therefore safe to conclude that on many trials the difference was detected but not identified.

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[1] Compare this statement with equation 9, section 3.5.3.

9.4 Discussion

9.4.1 High input loads and the whole-word theory

The prediction of the whole-word theory that performance with highly familiar words will rise above seven letters was clearly confirmed. With an ISI of 0 milliseconds subjects discriminated, on average, 8.9 of the 14 letters. With an ISI of 300 milliseconds subjects discriminated 11.3 of the 14 letters. In contrast only 4.3 of the 14 letters were identified in the LFI condition when the ISI was 0 milliseconds, and only 5.9 when it was 300 milliseconds. This shows clearly that in tasks involving continuous input the amount of stimulus information lost during processing depends predominantly upon the subject's prior experience with the stimulus material. The greater accuracy with which subjects reproduce familiar words is not predominantly due to the greater accuracy with which lost information is replaced when words are familiar. The results show also that the continuous and rapid extraction of information in normal reading requires the reduction of information loss by some form of trace-input matching. The subject would otherwise have available at most only 5.9 letters out of every 14. It can therefore be concluded that the effect of prior experience on the stimulus component of word recognition is a phenomenon of wide generality.

It must be noted that performance under the HFI condition was less efficient than might have been expected on the basis of earlier results. In experiment

2 performance in the HFD condition rose more-or-less linearly from 3.5 letters at 50 milliseconds to 5.9 letters at 70 milliseconds. If performance continued to rise at this rate far more than 8.9 letters would be extracted from two displays each lasting 100 milliseconds. This discrepancy might be due to the use of double presentations. On the other hand, it might be that no matter how 14 letters are presented HFD performance rises rapidly only for the first six letters. Both possibilities carry important implications and a study of HFD performance with higher input loads in a single presentation would therefore be of great interest.

9.4.2 The theory of special storage and erasure

The theory of special storage and erasure, which was proposed to explain how noise fields can reduce recognition accuracy without altering the letter position effect, was clearly confirmed. The amount of backward masking caused by a display containing letters was greater than that caused by a noise field. There are two main reasons for believing that this is the correct interpretation of the relation between the accuracy with which word 1 was reproduced and the ISI.[1] The first is that delaying the onset of word 2 by only 100 milliseconds largely removed the additional interference caused by its presentation. The second, is that the relation between performance and ISI was the same for both HFI and LFI conditions. This would

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[1] It is important to remember that the noise field was displayed during the ISI.

be expected if the interference caused by word 2 was due to masking, but not if it was due to changes in storage processes. Neither the superposition nor the substitution accounts of backward visual masking can explain the results. They appear to be explicable only in terms of a masking process that depends upon the identity of the masked and masking stimuli.

9.4.3 Read-out and letter position effects within words 1 and 2

The effect of letter position for word 1 in the LFI condition (shown in Figure 3) does not accord well with the notion that read-out involves scanning. If read-out does involve a sequential scanning process (scanning across letters in the LFI condition), and if a later display containing letters does mask the display that is scanned, then there will be some ISI's such that the masking interfers with recognition of the letters at the end of the word but not with those at the beginning. Accentuation of the letter position effect should therefore be observed for these ISI's. No such accentuation is apparent in the results reported above. It is possible that that accentuation was not observed because the rate of scanning is so high that there is only a narrow range of ISI's over which accentuation occurs. To test this explanation it would be necessary to make a more thorough investigation of the relation between ISI and the letter position effect for word 1.

The effect of letter position within word 2 also fails to accord well with the notion that read-out is a scanning process. If read-out involves a scanning process with a centre of focus constrained to move in an orderly manner across the visual display, then there will be some ISI's such that word 2 is present while the scan is at, or near, the end of word 1. In the present experiment word 2 was presented symmetrically across the same fixation point as word 1. Therefore, when word 2 is presented while the scan is near the end of word 1, the scan will be in the same position relative to word 2 as it is relative to a single word presented to the left of fixation. Harcum and Jones (1962) have shown that the letter position effect for words of eight letters presented to the left of fixation differs from that for words presented symmetrically across fixation. The letter position effect that they obtained was bow-shaped, but more nearly symmetrical, with performance worst at positions three and four, rather than at position seven as it is for words of eight letters presented symmetrically across fixation. This was clearly not the effect observed for word 2. It is possible, but perhaps unlikely, that eye-movements during the ISI could account for this failure to find any equivalence between the letter position effect for word 2 and that for words presented to the left of fixation. It seems more likely, particularly in view of the results of Bower (1965) mentioned in Chapter 8, that read-out does not involve a scanner constrained to move across the visual display.

9.5 Summary

The main conclusions drawn from experiment 5 are therefore as follows:

1. With high input loads HFI performance, as measured using the method of random changes, rises to at least eleven letters; LFI performance does not rise beyond six letters. This result supports the whole-word theory.

2. Letter displays are more effectively masked by letter displays than by noise fields. This result is a confirmation of the theory of special storage and erasure.

3. The effect of letter position within the first of two consecutively displayed words was not accentuated for any of the ISI's studied. This weakens, but does not disconfirm, the view that read-out is sequential.

4. On some 'different' trials the subject detects the difference but fails to identify it.

CHAPTER 10

SUMMARY AND SPECULATIONS

This thesis has demonstrated the possibility of obtaining unbiased measures of the information transmitted through the input processing systems. It has shown that even under conditions of optimum readiness the stimulus and supplementary components of word recognition performance can be separated. In addition it has tried to show how behavioural data can be used to determine where in the transmission sequence variables affecting the stimulus component operate. Pessimism concerning the possibility of obtaining 'pure' measures of 'perception' is therefore unwarranted. These measures have been difficult to obtain only because there has been a widespread reluctance to state the problem explicitly in terms of the information processing systems producing the observed performance.

10.1 The distribution of familiarity effects over the stimulus and supplementary components

The experiments of Spence (1963) and others (see p.32) have shown that the effects of word familiarity involve changes in the supplementary component. Experiments 2, 3, 4, and 5 have shown that the effects of word familiarity also involve changes in the stimulus component. This demonstration is the basic contribution offered by this thesis. Whether all familiarity effects are due to changes in input processing or to changes in supplementation is therefore no longer at issue. What is now at issue is the relative importance of the two kinds of change in any given class of situations. It appears likely that, in some situations, familiarity effects are predominantly due to changes in supplementation and, in others, to changes in input processing.

From the results of experiments 3, 4, and 5 it is reasonable to conclude that change in the stimulus component of word recognition as a result of prior experience is a common occurrence. Experiment 3 showed that the stimulus component can be increased by giving the subject only a few seconds experience of the displayed word. This increase however is small and unstable. It is clear from the results of experiment 4 that optimum readiness is not a necessary condition for prior experience to facilitate input processing. Performance with a comparator word chosen randomly from one of four was little different from that with a single comparator word. Thus, it is not necessary for the facilitation of input processing that the subject be prepared for a single word. Experiment 5 showed that in tasks involving high input loads prior experience of the displayed words produces a large reduction in information loss. The size of this reduction makes it reasonable to conclude that facilitation of input processing plays a major role in normal reading.

10.2 Some aspects of input processing and its facilitation by prior experience

Demonstration of the effect of prior experience on the stimulus component leads directly to the task of determining the mechanism of this effect. This section briefly summarizes the explanation offered in the preceeding chapters and then considers the various aspects of input processing in a little more detail.

Put most simply, the experiments reported above have shown that prior experience of the displayed words facilitates input processing by increasing the number of letters read out and by decreasing information loss during storage. These conclusions were drawn, in the first place, from the finding that both duration-sensitive and duration-insensitive performance are improved when highly familiar words are displayed. The view that duration-sensitive performance shows the number of letters read out is widely accepted, and the grounds for this view are, briefly, that such performance is controlled by variables unlikely to operate beyond the receptor systems, and that, as the storage and retrieval systems can handle four letters without loss, the loss must occur earlier when only one or two letters are recognized. If duration-sensitive performance does show the number of letters read out there is little doubt that more letters are read out if the displayed words are highly familiar. This conclusion carries far reaching implications. Some have already been mentioned, others will be mentioned in the discussion that follows.

The first and most important implication is that if the word displayed is sufficiently familiar word identity is computed within the receptor systems. This implication was shown by noting that only if the input is classified as a single particular word prior to read-out could familiarity affect read-out in the manner observed. It was further argued that, for the words used in the above experiments at least, this classification could not be a schematic one, differentiating between familiar and unfamiliar words on the basis of limited properties of the words, because there were no such differentiating limited properties.

It is important to make clear exactly what is implied by the claim that the input is classified as a particular word within the receptor systems. It will be remembered that the receptor systems are those whose states continually depend upon the sensory input. The above claim is therefore equivalent to the claim that, for each familiar word, there is a physiological unit whose activity continually depends upon retinal input, and which takes a particular state only if the input contains that particular word. In other words, there are units which signal the presence of particular words in the current sensory input.

As already mentioned, this general picture of the way in which prior experience changes input processing to improve word recognition performance is essentially the whole-word theory of Woodworth and J. McKeen Cattell, which was described in Section 1.2.1. Further evidence in support of this theory was reported in Chapter 8. It was noted that if familiar words are read out as the result of a single classification then this will remove those differences between individual letters that arise after read-out. Using the data provided by experiment 2 the effects of letter position under high familiarity and under low familiarity conditions were compared. As predicted by the whole-word theory the effects of letter position largely disappeared under high familiarity conditions.

If the above account is correct then there will clearly be classifying units for many other properties, some innate and some learned. Subjects have had, for example, far more experience of letters than of words. It is, therefore, reasonable to assume that units classifying letters exist within the receptor systems. To develop these classifying units independently of each other would be most inefficient, and it is therefore likely that the outputs of units reacting to relatively simple properties will serve as the inputs for units reacting to properties that are more complex. For the early stages of sensory processing involving the relatively simple innately computed properties this is already known to be the case (Hubel, 1963). A clear description of the kind of organization proposed is given by Attneave:

> 1. The basic idea of 'levels' or of a 'perceptual hierarchy', is simply that a potentially definable sequence of classifications of incoming information occurs. It is presumed that the output of one stage of this sequence constitutes the input of the next, but the possibility of feedback from higher to lower levels is by no means to be excluded.
>
> For example, activity of a particular element on one level might imply (i.e. result from) a pattern of activity of elements on the next lower level describable as follows: 'A and C but not B and not D, or E and G but not F and not H, or ...,' etc. The conjunctive terms involve grouping of elements (receptors, at the lowest level); the disjunctive terms grouping of states.

> On this basis it is evident that a higher-level element may represent a relation between lower-level elements, if the latter are ordered.
>
> 2. It will be true, at least in a statistical sense, that higher-level classifications will represent, or depend upon, the states of larger subsets of receptors than lower-level classifications. Such an increase in extensity of representation is obvious in the case of a hierarchy like active receptor-line-letter-word-phrase. Likewise, higher-level categories will tend to have lower individual probabilities i.e., to be more specific to the total receptor-state and accordingly to carry more information. (Attneave, 1962, p.639).

It is important to note that it is probable that there are units of classification intermediate between letters and words, such as units classifying syllables. A test of this could easily be made. The number of letters read out (as shown by duration-sensitive performance) under LFI conditions, could be studied, using the correction procedures developed in Chapter 3, for words having the structure CVCVCVC, and for words having the structure CCCCVVV. If more letters were read out from words of the first kind it would indicate that syllabic coding occurs before read-out.

One important property that has not yet been mentioned is the relative positions of any letters identified. It was seen in experiment 2 that nearly all letters correctly identified were also reproduced in their correct relative positions. Many theories of pattern recognition are unable to account for this simple fact. If, for instance, letter recognition occurred as the result of some kind of 'resonance' between trace and input, the subject could say that such-and-such letters were in the visual field, but would have no way of knowing their relative positions. In order to provide information regarding position in combination with that regarding identity a hierarchical classifying system must reduplicate its classifying units for each of a number of 'retinal regions'. The activity of particular letter classifying units would therefore depend not only upon the presence of a particular pattern but also upon its position.

If these speculations are correct then it is possible that the mutual masking observed by Woodworth (1938), and the resolution limitations observed by Averbach and Coriell (1961), are due to limitations in the number of such regions available within any given area.

The system thus far proposed is one in which current stimulation is represented by the activity of large numbers of hierarchically organized classifying units, each signalling the presence of a particular property. In Chapter 8 it was further suggested that these units have short term storage capacities but are inhibited by new input of the appropriate type. This theory of special storage and erasure was proposed to explain how, even in the presence of post-stimulus 'noise' fields, read-out could occur after stimulation. It was confirmed by the results of experiment 5, which showed that a display containing letters was more effectively erased by a display containing letters than by a 'noise' field. It is important to note that both hierarchical processing and the occurrence of learned transformations prior to read-out are essential aspects of the theory of special storage and erasure - erasure within the receptor systems can be dependent only on the properties computed within those systems. The results of experiment 5 are also, therefore, further evidence that processing in the receptor systems is both hierarchical and developed by experience.

Exactly what prior experience is necessary for the development of sensory classifying units is still not known. It appears that the prior experience given in the high familiarity conditions of experiments 2, 4, and 5 was sufficient, and that the 11 seconds given in experiment 3 was not. If this outcome is replicated it will lend further force to the view that familiarity effects on the stimulus component are due to the development of sensory classifying units. What is now required to pin down the crucial aspects of prior experience is repetition of experiment 2 using many variations in the familiarization procedures. Of particular interest is the modality, duration, and temporal patterning of the prior experience. It is also of interest to know whether prior experience of words printed in one way will effect the stimulus component of recognition when those words are displayed printed in a quite different way. The results of such research might well demand revision of the views offered in this thesis.

If processing within the receptor systems is hierarchical, then the amount of learning necessary to develop a classifying unit for a particular stimulus will depend upon the subject's prior experience with parts of the stimulus. This prediction could be tested by comparing the amounts of learning required to increase the read-out rates for stimuli which vary according to the subject's experience of the parts from which they are constructed.

It is clear that if the receptor systems are organized as described above then read-out must be possible from many different levels, and not just from the most complex. If this is so then read-out must be much more than a process selecting items according to their position within a two dimensional spatial array, for it must also be able to switch from one level to another. How this is achieved and how long switching from one level to another takes is still uncertain. Other unsolved problems concerning read-out were mentioned in Chapters 8 and 9.

A particularly interesting problem not yet mentioned is that of timing. It is reasonable to assume that the probability of a correct classification of the input at the letter level will increase with the time from the onset of the display. If read-out is initiated too early the benefit of any continuing input will be lost. If, on the other hand, read-out is initiated too late any information stored in the letter, or word, classifiers may have decayed or have been erased by later input. It is possible that in normal reading tasks this dilemma is resolved by keeping fixation time, and thus the time between displays, relatively constant. Fixation time in normal reading is about 200 milliseconds, and saccad time about 20 milliseconds (Woodworth, 1938). If read-out could be performed within 20 milliseconds, therefore, it could be initiated consistently 200 milliseconds after the onset of each display. This possibility is particularly attractive because it was found in experiment 5 that word 2 interfered with the recognition of word 1 only if it was displayed within 200 milliseconds of the onset of word 1.

In the model for visual memory tasks proposed by Sperling (1963), the store into which information is read-out is an acoustic store to which is coupled a rehearsal process which can restore fading acoustic images. This view is in keeping with the acoustic confusions in visual immediate memory tasks observed by Conrad (1964). The whole-word theory implies that errors under high familiarity conditions occur only during read-in to the word classification levels in the visual receptor systems. These errors should therefore not show signs of deterioration during storage in an acoustic form. A test of this prediction could easily be made by comparing the confusion matrices obtained under high and under low familiarity conditions. Casual observations made during the course of the experiments reported above suggest that the two confusion matrices do indeed differ in the predicted manner. A more thorough investigation would clearly be both simple and important.

10.3 Some major remaining problems

This thesis has ignored many crucial aspects of word recognition. Any explanation of the effects of prior experience must be weak, unless it is given as part of a more complete account of information processing in word recognition than that here offered.

Information processing in the reception systems, for example, must be described more fully. Thus it is necessary to discover exactly what information is extracted at each stage of processing. The account of this aspect of the processing would perhaps best be given as sets of rules showing how the many isolated events initiated directly by stimulation are combined to produce single events isomorphic with stimulus identity. Furthermore, it is necessary to discover, for each level of processing, the quantitative aspects of the storage, erasure, and read-in functions. Only then will it be possible to know what processing will occur under particular conditions. It will also be necessary to determine whether any of the quantitative aspects of the storage, erasure, and read-in functions within the reception systems, are centrally controlled in accordance with context, meaning, or motivation. The account of this aspect of the processing would perhaps best be given as statements of the conditions of activation of those units whose patterns of activity potentially fulfill the rules of information extraction.

The methods developed in this thesis suggest how such an account of reception, and similar accounts of read-out and storage, could be achieved. It is probable that in any such account the explanation that has been offered for the effects of prior experience on the stimulus component would be extensively modified. That prior experience does affect the stimulus component of word recognition performance can, however, no longer be reasonably doubted.

APPENDIX 1

EXPERIMENT 1

APPENDIX 1

EXPERIMENT 1

The words used in Experiment 1

SET			
1	1′	2	2′
JANDARA	JAMPARA	KADIRGA	KADESGA
AFWORBU	AFCARBU	ADAFNAW	ADIFPAW
BIWOJNI	BIWASNI	BORULCE	BODILCE
NANSOMA	NASTOMA	NIJARON	NIJIMON
OLMADIK	OLDABIK	ENSHIMI	ENSTAMI
AKLIYAT	AKTOYAT	INKULAM	INDURAM
SARICIK	SASIMIK	TAVHANE	TAWSANE
SABULON	ZABETON	UDIBNON	UDOBRON
CIVADRA	CIVBURA	DILIKLI	DILEGLI
LOKANTA	LORASTA	MECBURI	MELBORI

The words in sets 1 and 2 were words used by Solomon and Postman (1952). The words in sets 1′ and 2′ were formed from these by changing two of the three middle letters.

TABLE 1: RECOGNITION THRESHOLDS FOR THE REHEARSED WORDS (IN MILLISECONDS)

Each subject recognized two words at each rehearsal frequency.

	REHEARSAL FREQUENCY									
	25		10		5		2		1	
SUBJECT	1	2	1	2	1	2	1	2	1	2
1	40	60	70	60	80	50	60	70	50	100
2	230	300	180	350	350	100	250	750	600	700
3	120	130	80	140	140	110	110	90	300	200
4	80	70	90	160	70	160	220	100	200	160
5	90	70	80	110	350	90	90	250	200	160
6	110	160	100	130	180	120	120	140	100	160
7	80	350	80	500	90	50	60	180	1000	150
8	250	90	100	150	80	80	100	90	280	900
9	230	230	230	230	300	250	300	330	400	280
10	100	50	70	100	190	80	50	110	100	70
11	60	130	60	60	60	160	100	170	90	200
12	170	280	300	250	550	280	450	330	1000	330
13	90	80	110	350	130	60	140	480	280	110
14	60	50	80	70	80	60	70	90	90	80
15	160	380	180	480	230	160	300	190	900	280
16	170	50	80	90	120	130	160	80	130	180
17	70	50	50	50	60	50	60	70	100	110
18	100	90	100	150	90	60	100	100	130	130
19	50	60	50	130	90	200	150	60	90	200
20	60	110	50	80	130	230	190	380	150	100

TABLE 2: RECOGNITION THRESHOLDS FOR THE MATCHED WORDS (IN MILLISECONDS)

Each subject recognized two words at each rehearsal frequency.

	COMPETITOR REHEARSAL FREQUENCY									
	25		10		5		2		1	
SUBJECT	1	2	1	2	1	2	1	2	1	2
1	110	90	70	80	90	130	60	80	100	70
2	150	800	700	400	300	400	500	180	350	100
3	500	400	150	150	480	400	230	180	250	230
4	140	120	160	180	180	300	300	140	160	260
5	650	380	500	230	140	200	450	380	430	280
6	190	140	100	180	180	170	130	140	120	120
7	130	1000	800	100	850	230	400	130	200	150
8	450	170	120	110	170	210	675	170	190	380
9	330	600	450	330	480	350	400	550	800	480
10	110	90	700	50	180	120	130	150	160	100
11	50	220	230	150	160	50	120	150	150	130
12	800	1000	600	750	1000	900	550	550	750	850
13	150	150	350	170	150	150	380	170	180	160
14	200	140	140	110	500	130	100	130	110	110
15	250	450	430	250	600	800	190	170	380	300
16	230	160	140	230	450	190	250	400	140	280
17	130	70	150	120	180	130	110	90	120	70
18	100	130	170	170	650	80	120	100	110	170
19	130	120	180	200	350	160	190	380	250	200
20	330	550	480	250	120	150	110	150	150	190

TABLE 3: RECOGNITION THRESHOLDS FOR THE CONTROL WORDS (IN MILLISECONDS)

Each subject recognized ten control words.

SUBJECT	CONTROL WORD THRESHOLDS									
	1	2	3	4	5	6	7	8	9	10
1	120	90	90	130	70	240	80	250	150	170
2	300	850	280	700	350	550	650	500	850	700
3	190	430	400	380	350	400	500	350	420	350
4	260	480	220	340	360	520	180	480	480	300
5	430	450	230	450	140	190	480	280	430	280
6	230	150	180	190	170	140	530	350	180	450
7	280	650	990	900	300	550	850	330	450	990
8	200	330	350	100	150	230	300	430	380	300
9	430	450	400	600	230	330	600	480	450	600
10	300	110	140	110	140	130	90	250	180	150
11	190	80	90	150	250	150	170	80	130	950
12	800	450	280	550	850	500	200	800	800	900
13	120	100	100	150	230	140	180	330	330	990
14	100	140	130	150	120	130	120	160	160	170
15	650	450	400	400	550	750	430	550	380	990
16	150	200	230	280	120	120	150	700	190	120
17	70	170	130	180	180	110	400	230	110	160
18	140	160	330	170	160	110	150	200	150	150
19	140	170	130	150	100	90	100	200	120	230
20	100	170	230	160	120	160	190	190	180	330

TABLE 4: REJECTION THRESHOLDS AND THE ASSOCIATED RECOGNITION THRESHOLDS FOR THE MATCHED WORDS (ALL IN MILLISECONDS)

Rej = Rejection threshold. A blank in this column indicates that no overt-intrusion occurred.

Rec = Recognition threshold for the matched word.

	REHEARSAL FREQUENCY									
	25		10		5		2		1	
SUBJECT	Rej	Rec	Rej	Rec	Rej	Rec	Rej	Rec	Rej	Rec
1	50	100	50	60	70	90	–	70	60	90
	60	70	50	80	–	130	–	80	–	110
2	–	350	–	500	150	300	100	700	–	150
	–	100	–	180	–	400	–	400	–	800
3	120	250	110	230	240	480	–	150	–	500
	–	230	–	180	–	400	–	150	–	400
4	–	160	150	300	–	180	480	160	–	140
	–	260	–	140	280	300	–	180	100	120
5	80	430	130	450	130	140	–	500	550	650
	90	280	330	380	–	200	200	230	180	380
6	140	120	110	140	140	180	–	100	–	190
	150	120	–	130	110	170	150	180	80	140
7	150	200	–	400	200	230	–	800	–	130
	110	150	110	130	–	850	280	100	150	1000
8	–	190	–	670	190	170	100	110	–	450
	–	380	180	170	230	210	–	120	150	170
9	380	800	–	400	–	480	650	450	200	600
	380	480	230	550	300	350	–	330	–	330
10	–	100	–	130	–	180	–	700	60	110
	–	160	–	150	–	120	30	50	–	90
11	110	150	70	120	–	50	30	150	–	50
	120	130	80	150	–	160	170	230	180	220
12	700	750	–	550	550	1000	–	750	280	1000
	250	850	–	550	380	900	380	600	–	800
13	–	160	–	380	140	150	200	350	–	150
	–	180	130	170	–	150	140	170	–	150
14	–	110	–	130	150	500	–	140	180	200
	–	110	–	100	–	130	60	110	–	140
15	250	380	–	170	–	800	300	430	–	250
	–	300	–	190	–	600	200	250	–	450
16	–	140	380	400	–	450	–	230	–	160
	250	280	230	250	–	190	–	140	100	230
17	–	70	–	110	120	130	110	150	50	70
	100	120	110	90	170	180	–	120	–	130
18	190	170	–	100	480	650	160	170	–	100
	130	110	–	120	–	80	–	170	–	130
19	110	250	60	380	180	160	–	180	90	120
	80	200	90	190	80	350	130	200	120	130
20	160	190	90	110	50	150	120	250	–	330
	170	150	80	150	110	120	100	480	400	550

APPENDIX 2

EXPERIMENT 2

TABLE 1: THE ORDERS IN WHICH SUBJECTS PERFORMED UNDER THE THREE CONDITIONS

H = High familiarity discriminations.

L = Low familiarity discriminations.

I = Low familiarity identifications.

SUBJECT	SESSION	ORDER	SUBJECT	SESSION	ORDER
1	1	HLIILH	2	1	LIHHIL
	2	LIHHIL		2	IHLLHI
	3	IHLLHI		3	HLIILH
	4	IHLLHI		4	HLIILH
	5	LIHHIL		5	IHLLHI
	6	HLIILH		6	LIHHIL
3	1	IHLLHI	4	1	ILHHLI
	2	HLIILH		2	LHIIHL
	3	LIHHIL		3	HILLIH
	4	LIHHIL		4	HILLIH
	5	HLIILH		5	LHIIHL
	6	IHLLHI		6	ILHHLI
5	1	LHIIHL	6	1	HILLIH
	2	HILLIH		2	ILHHLI
	3	ILHHLI		3	LHIIHL
	4	ILHHLI		4	LHIIHL
	5	HILLIH		5	ILHHLI
	6	LHIIHL		6	HILLIH

TABLE 2: TOTALS AND SUB-TOTALS OF CORRECT AND INCORRECT RESPONSES

LFD CONDITION

Same = 'same' trials.
Total = all trials.
C = correct.
Diff = 'different' trials.
1 = incorrect.

SUBJECT	DURATION (MILLISECS)	Same		Diff		Total	
		C	1	C	1	C	1
1	50	31	23	34	21	65	44
	55	39	21	26	25	65	46
	60	41	19	31	14	72	33
	70	44	31	18	14	62	45
	90	44	19	29	13	73	32
	200	50	8	37	11	87	19
2	50	31	12	30	20	61	32
	55	44	18	28	18	72	36
	60	49	19	25	14	74	33
	70	46	21	23	15	69	36
	90	46	15	32	13	78	28
	200	50	9	45	8	95	17
3	50	46	10	22	26	68	36
	55	55	10	19	21	74	31
	60	63	13	15	16	78	29
	70	46	13	18	28	64	41
	90	52	6	33	18	85	24
	200	54	2	41	13	95	15

(continued on next page)

TABLE 2 (continued)

SUBJECT	DURATION (MILLISECS)	Same		Diff		Total	
		C	1	C	1	C	1
4	50	37	23	17	32	54	55
	55	46	15	15	30	61	45
	60	62	13	14	20	76	33
	70	48	12	17	27	65	39
	90	52	10	20	26	72	36
	200	51	7	37	17	88	24
5	50	36	22	21	30	57	52
	55	44	18	27	20	71	38
	60	47	17	17	25	64	42
	70	54	17	15	20	69	37
	90	54	7	25	19	79	26
	200	49	7	31	21	80	28
6	50	36	22	25	28	61	50
	55	42	20	27	19	69	39
	60	37	23	17	26	54	49
	70	50	25	17	17	67	42
	90	43	18	23	22	66	40
	200	49	5	35	14	84	19

TABLE 3: TOTALS AND SUB-TOTALS OF CORRECT AND INCORRECT RESPONSES

HFD CONDITION

Same = 'same' trials.
Diff = 'different' trials.
Total = All trials.
C = correct.
1 = incorrect.

SUBJECT	DURATION (MILLISECS)	Same		Diff		Total	
		C	1	C	1	C	1
1	50	36	21	37	14	73	35
	55	40	20	41	11	81	31
	60	47	13	44	9	91	22
	70	52	14	47	1	99	15
	90	45	12	53	4	98	16
	200	50	7	53	2	103	9
2	50	44	16	41	16	85	32
	55	41	11	55	10	96	21
	60	45	15	47	7	92	22
	70	49	14	53	4	102	18
	90	48	15	48	4	96	19
	200	55	4	54	3	109	7
3	50	32	22	50	8	82	30
	55	37	23	46	7	83	30
	60	35	30	43	4	78	34
	70	42	22	48	3	90	25
	90	50	4	61	1	111	5
	200	51	5	54	0	105	5

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TABLE 3 (continued)

SUBJECT	DURATION (MILLISECS)	Same		Diff		Total	
		C	1	C	1	C	1
4	50	51	17	23	23	74	40
	55	45	13	25	28	70	41
	60	59	9	32	10	91	19
	70	47	9	44	15	91	24
	90	50	10	44	11	94	21
	200	51	6	56	1	107	7
5	50	37	18	30	27	67	45
	55	54	14	31	15	85	29
	60	49	16	31	18	80	34
	70	58	9	36	11	94	20
	90	62	2	44	9	106	11
	200	46	4	58	7	104	11
6	50	37	18	36	22	73	40
	55	40	15	38	20	78	35
	60	38	19	38	15	76	34
	70	47	11	47	9	94	20
	90	51	10	39	13	90	23
	200	55	2	55	4	110	6

TABLE 4: THE TOTAL NUMBER OF LETTERS CORRECTLY REPRODUCED AND IN THE CORRECT POSITION

LFI CONDITION

Number of trials per cell = 60.
The average value of Sp for each cell = $\frac{\text{Number correct}}{60}$

	DURATION IN MILLISECONDS																				
	50							55							60						
	LETTER POSITION							LETTER POSITION							LETTER POSITION						
SUBJECT	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
1	28	28	16	17	8	20	8	39	42	31	32	12	25	13	45	40	27	32	18	18	19
2	48	42	28	32	20	16	13	46	53	36	26	17	24	19	51	49	31	19	21	15	19
3	38	45	27	25	7	29	20	51	51	31	35	10	23	23	56	52	35	33	29	23	34
4	22	30	17	17	6	16	6	25	27	23	28	12	21	6	31	45	24	26	18	18	14
5	38	32	8	25	12	18	17	48	35	16	26	13	18	23	51	40	24	20	19	23	29
6	14	18	9	19	13	14	5	21	34	19	20	9	17	5	31	34	22	35	12	25	4

(continued on next page)

TABLE 4 (continued)

	DURATION IN MILLISECONDS																				
	70							90							200						
	LETTER POSITION							LETTER POSITION							LETTER POSITION						
SUBJECT	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
1	54	52	41	36	29	28	27	54	53	45	28	27	36	35	59	56	53	51	50	38	54
2	53	53	35	27	19	18	23	55	55	45	34	27	23	24	57	54	46	39	39	28	44
3	55	54	36	43	22	28	26	58	56	44	50	31	38	32	60	59	54	54	46	51	46
4	42	43	38	32	25	26	17	48	51	35	42	21	32	24	52	56	50	52	43	31	40
5	52	38	24	30	19	18	31	55	48	33	31	32	25	41	59	56	43	43	41	36	42
6	44	44	24	37	17	26	12	50	49	36	46	26	33	17	58	58	52	54	32	44	30

TABLE 5: THE TOTAL NUMBER OF LETTERS CORRECTLY REPRODUCED IRRESPECTIVE OF POSITION

LFI CONDITION

Number of trials per cell = 60.
The average value of Sc for each cell = $\frac{\text{Number correct}}{60}$

Correct reproductions are entered according to the position in which they were written by the subject.

	DURATION IN MILLISECONDS																				
	50							55							60						
	LETTER POSITION							LETTER POSITION							LETTER POSITION						
SUBJECT	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
1	33	35	35	35	21	33	17	42	48	40	39	24	32	21	48	46	36	41	31	27	25
2	51	45	35	39	30	21	19	48	55	43	33	25	32	25	52	53	39	29	30	23	23
3	39	53	38	38	21	35	26	54	55	44	46	22	38	26	57	55	39	45	35	33	37
4	30	36	28	26	18	21	8	31	32	31	38	15	26	11	36	49	37	32	25	26	22
5	41	37	18	32	24	27	22	49	41	20	31	26	32	27	51	44	30	29	27	32	34
6	19	28	21	29	22	17	9	23	41	26	29	19	32	13	38	44	31	41	23	31	15

(continued on next page)

TABLE 5 (continued)

	DURATION IN MILLISECONDS																				
	70							90							200						
	LETTER POSITION							LETTER POSITION							LETTER POSITION						
SUBJECT	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
1	54	55	47	42	45	32	34	54	55	53	39	37	45	40	59	58	56	55	51	40	54
2	54	56	47	36	30	26	26	55	55	50	41	40	29	29	57	56	54	43	52	35	53
3	58	55	46	50	30	33	28	58	58	52	54	37	38	36	60	60	56	58	49	53	49
4	43	50	43	38	32	33	19	48	54	45	44	28	37	25	58	56	55	55	47	32	43
5	53	47	32	42	34	24	37	56	52	39	46	36	34	43	59	57	50	46	46	41	44
6	44	49	32	41	28	32	19	51	54	47	52	34	39	19	58	59	56	56	46	46	34

APPENDIX 3

EXPERIMENT 3

TABLE 1: THE NUMBERS OF CORRECT AND INCORRECT RESPONSES FOR EACH SUBJECT AND CONDITION

ALL TRIALS

C = correct.
I = incorrect.

	PRIOR EXPERIENCE OF COMPARATOR WORD (SECONDS)					
	0		1		11	
SUBJECT	C	I	C	I	C	I
1	39	16	45	10	45	7
2	33	19	40	15	37	18
3	38	17	38	14	38	17
4	31	21	40	15	31	24
5	40	15	43	12	42	10
6	29	26	35	17	42	13
7	42	13	54	1	47	5
8	35	17	41	14	42	13
9	37	18	43	9	40	15
10	34	18	41	14	35	20
11	36	19	35	20	24	28
12	32	23	41	11	44	11

TABLE 2: THE NUMBERS OF CORRECT AND INCORRECT RESPONSES FOR EACH SUBJECT AND CONDITION

'SAME' TRIALS

C = correct.
I = incorrect.

	PRIOR EXPERIENCE OF COMPARATOR WORD (SECONDS)					
	0		I		11	
SUBJECT	C	I	C	I	C	I
1	24	5	27	2	26	2
2	17	11	27	2	27	2
3	26	3	26	2	24	5
4	20	8	21	8	24	5
5	25	4	27	2	26	2
6	16	13	19	9	26	3
7	18	11	28	1	26	2
8	20	8	24	5	27	2
9	18	11	25	3	22	7
10	20	8	25	4	24	5
11	22	7	23	6	17	11
12	14	15	22	6	27	2

TABLE 3: THE NUMBERS OF CORRECT AND INCORRECT RESPONSES FOR EACH SUBJECT AND CONDITION

'DIFFERENT' TRIALS

C = correct.
I = incorrect.

SUBJECT	PRIOR EXPERIENCE OF COMPARATOR WORD (SECONDS)					
	0		1		11	
	C	I	C	I	C	I
1	15	11	18	8	19	5
2	16	8	13	13	10	16
3	12	14	12	12	14	12
4	11	13	19	7	7	19
5	15	11	16	10	16	8
6	13	13	16	8	16	10
7	24	2	26	0	21	3
8	15	9	17	9	15	11
9	19	7	18	6	18	8
10	14	10	16	10	11	15
11	14	12	12	14	7	17
12	18	8	19	5	17	9

APPENDIX 4

EXPERIMENT 4

TABLE 1: NUMBERS OF CORRECT AND INCORRECT RESPONSES FOR EACH SUBJECT AND CONDITION

ALL TRIALS

C = correct.
I = incorrect.

	NUMBER OF ALTERNATIVE COMPARATOR WORDS					
	2×10^7		4		1	
SUBJECT	C	I	C	I	C	I
1	23	12	33	5	32	6
2	16	20	31	6	32	4
3	24	12	25	12	33	5
4	25	11	37	2	33	6
5	29	9	33	5	35	2
6	18	17	18	20	26	14
7	27	8	31	7	33	5
8	21	15	27	10	28	8
9	33	3	30	7	33	5
10	24	12	34	5	37	2
11	26	12	34	4	28	9
12	25	10	30	8	36	4

TABLE 2: THE NUMBERS OF CORRECT AND INCORRECT RESPONSES FOR EACH SUBJECT AND CONDITION

'SAME' TRIALS

C = correct.
I = incorrect.

	NUMBER OF ALTERNATIVE COMPARATOR WORDS					
	2×10^7		4		1	
SUBJECT	C	I	C	I	C	I
1	13	4	19	1	19	0
2	6	11	15	4	16	3
3	9	10	15	8	15	3
4	17	2	21	0	17	1
5	16	2	16	3	18	1
6	7	9	11	7	16	4
7	13	4	15	5	18	1
8	14	3	18	1	18	1
9	17	2	20	3	15	3
10	13	6	19	2	17	1
11	10	8	19	0	19	0
12	12	4	15	3	18	2

TABLE 3: THE NUMBER OF CORRECT AND INCORRECT RESPONSES FOR EACH SUBJECT AND CONDITION

'DIFFERENT' TRIALS

C = correct.
I = incorrect.

SUBJECT	NUMBER OF ALTERNATIVE COMPARATOR WORDS					
	2×10^7		4		1	
	C	I	C	I	C	I
1	10	8	14	4	13	6
2	10	9	16	2	16	1
3	15	2	10	4	18	2
4	8	9	16	2	16	5
5	13	7	17	2	17	1
6	11	8	7	13	10	10
7	14	4	16	2	15	4
8	7	12	9	9	10	7
9	16	1	10	4	18	2
10	11	6	15	3	20	1
11	16	4	15	4	9	9
12	13	6	15	5	18	2

APPENDIX 5

EXPERIMENT 2
LETTER POSITION EFFECTS

TABLE 1: THE PROPORTIONS OF INCORRECT RESPONSES ON 'DIFFERENT' TRIALS SHOWN ACCORDING TO THE LETTER POSITION AT WHICH THE CHANGE OCCURRED

Display durations 50, 55, and 60 milliseconds combined.

HFD CONDITION

SUBJECT	LETTER POSITION						
	1	2	3	4	5	6	7
1	.06	.36	.28	.21	.16	.22	.30
2	.13	.04	.05	.17	.14	.34	.38
3	.03	.06	.53	.05	.15	.07	.13
4	.44	.20	.29	.31	.69	.59	.56
5	.20	.67	.21	.52	.48	.57	.32
6	.48	.61	.28	.23	.44	.04	.30

TABLE 2: THE PROPORTIONS OF INCORRECT RESPONSES ON 'DIFFERENT' TRIALS SHOWN ACCORDING TO THE LETTER POSITION AT WHICH THE CHANGE OCCURRED

Display durations 50, 55, and 60 milli-seconds combined.

LFD CONDITION

	LETTER POSITION						
SUBJECT	1	2	3	4	5	6	7
1	.19	.32	.24	.53	.54	.71	.43
2	.00	.00	.14	.69	.52	.62	.67
3	.13	.24	.58	.50	.60	.92	.73
4	.36	.50	.65	.83	.73	.63	.81
5	.22	.44	.50	.71	.75	.58	.61
6	.42	.29	.48	.56	.40	.78	.63

APPENDIX 6

EXPERIMENT 5

TABLE 1: THE NUMBERS OF CORRECT AND INCORRECT RESPONSES IN THE HFI CONDITION FOR EACH SUBJECT AND ISI

C = correct. I = incorrect.
Same = 'same' trials. Diff = 'different' trials.

		INTER-STIMULUS INTERVAL (MILLISECONDS)							
		0				40			
		Word 1		Word 2		Word 1		Word 2	
SUBJECT		same	Diff	same	Diff	same	Diff	same	Diff
1	C	13	23	17	25	18	20	14	21
	I	11	6	11	1	5	10	12	5
2	C	14	19	19	21	18	19	17	24
	I	10	11	8	6	10	8	10	4
3	C	13	26	21	22	17	27	16	15
	I	12	2	6	6	6	5	12	9
4	C	16	17	22	16	22	19	22	19
	I	9	11	8	10	3	10	5	9
		100				300			
1	C	18	24	11	24	12	28	16	26
	I	8	2	13	5	12	1	12	2
2	C	15	26	18	17	23	25	17	22
	I	7	4	11	9	3	5	12	3
3	C	16	23	20	22	17	30	21	21
	I	9	4	7	6	6	1	6	4
4	C	21	24	21	14	27	20	19	18
	I	3	6	8	12	1	8	7	9

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