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# WORD DISCRIMINATION : A STUDY OF THE ROLE OF PRIOR EXPERIENCE IN THE PROCESSING OF BRIEFLY AVAILABLE VISUAL INFORMATION

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## ABSTRACT

Briefly displayed words are far more accurately recognized if the words displayed are familiar. Although well established, this phenomenon has not yet been adequately explained. Word recognition performance combines two components: the stimulus component, comprising information received from the stimulus and transmitted into the response; and the supplementary component, comprising additional information supplied by the subject. Techniques currently available do not enable these two components to be separated. It has therefore not been possible to determine how the effects of familiarity are distributed across the two components. This thesis describes techniques which do provide such a separation.

Employing these techniques it is clearly shown that the effects of familiarity include changes in the stimulus component. Investigations of the mechanism of these changes in the stimulus component then show that the input is identified as a single particular word within the reception systems. The improvement in recognition performance results from the ensuing reduction in read-out and storage load. These findings constitute a confirmation of Woodworth's whole-word theory.

# CHAPTER 1

## THE PROBLEM

Human action proceeds in highly efficient co-ordination with many aspects of a rich and changing environment. The information about the environment which this achievement demands must be extracted from the input of some three million sensory fibres. Few of the nearly infinite number of input properties which could be extracted have any functional value, and selection of those that are useful is essential for efficient behaviour. This selection must be largely genetically determined, but a system which enabled new properties of the input to be extracted, on the basis of individual experience, would have great advantages over one that did not. Individual adaptation is of course a general phenomenon, but it has been widely assumed to result only from learning new relations between old properties, rather than from changing the properties used. This latter possibility is also important with respect to the nature of the processes extracting the properties from the input. In a system developed by individual experience, these processes would differ markedly from those in a system determined by genetics alone.

Important though this issue is, the technical difficulties are such that neither the nature nor the extent of the dependence of input processing on individual experience have been at all clearly determined. The basic difficulty is that the only evidence available and relevant is behavioural, whereas the issue is concerned with processes that are central. Furthermore, neither physiological nor psychological experiments with animals can provide conclusive evidence of the importance of perceptual learning in man. Man makes use of environmental properties which are particularly subtle, complex and idiosyncratic; it may well be that perceptual development through individual experience is far more important in man than in other animals. Extensive experimental control of the environment in which humans develop is not feasible, however, and the amount of experimentally controlled experience will often be negligible in comparison with the background of everyday experience. Everyday experience is itself difficult to treat as an experimental variable, and so the experimenter is left with experimental effects which are often small and unreliable.

Even if experimental changes in performance are produced we are faced with a fundamental difficulty of interpretation. Is the change in performance due to the extraction of new properties from the input, or to the occurrence of new responses to the old properties? Consider, for example, the results obtained by Leeper (1935). He reports that exposure to incomplete figures, supplemented by a verbal description of the associated complete figure, increases the probability that a person will 'see' the complete figure in the incomplete one. Is this because the person learns to put the input together in a new way, or is it only because he learns a new verbal response to the input analyzed as before? Similarly, Von Senden (1960) reports that adults who have had congenital cataracts removed are unable to recognize simple shapes and objects. Is this because they have not learned to extract the relevant visual properties, or because they have not learned to call these properties 'round' or 'square'?

In spite of these difficulties of interpretation, considerable advance has been made in discovering the relation between prior experience and performance in perceptual tasks. A wide variety of prior experiences have been used, and their effects have been studied on many perceptual phenomena: e.g. the recognition of words presented visually or acoustically, the perception of form, the perceptual constancies, the visual illusions, depth perception, and the appearance of stabilized retinal images. Extensive reviews of the findings of such research are given by Ammons (1954) and by Wohlwill (1960). The recent discussions by Fantz (1965) and by Postman (1963) provide particularly close analyses of the methodological and interpretive problems.

Word recognition differs from the other phenomena in a number of important respects, and these differences give word recognition a particular significance in the study of perceptual learning:

(a) Words, being culturally determined, have just the kind of regularity which can be utilized only by post-embryonic development.

(b) Language is unique to man, and may well be due in part to a particular capacity for post-embryonic perceptual development.

(c) Since J. McKeen Cattell's experiments in 1885, performance in word recognition has been known to be highly dependent on individual learning. With this phenomenon at least, experimental effects are large and reliable.

(d) The interpretive issue is particularly clear, and the inconclusiveness of performance change in word recognition as evidence of perceptual learning is at the centre of much recent debate. The difficulty is generally believed to result from the fact that some recognition responses are more likely to occur than others, quite independently of information from the stimulus. Therefore it is referred to as the problem of response bias.

(e) Presenting a set of items, and then noting the accuracy of the subject's reproduction, is a procedure common to experiments on word recognition and to experiments on verbal learning. When in addition prior training is given on the word to be

> recognized, the methodological continuity between the word recognition situation and traditional learning situations is particularly clear.

In addition, the restricted viewing conditions used in most studies of word recognition are of significance in that individual experience may function primarily to make reactions to particular environmental characteristics quicker, easier, or more efficient. If this is the case, and in word recognition at least there is good evidence that it is, then the effects of individual experience will be seen, not in the perceptions attained, but in the rate of attaining them. It is this point which gives importance to procedures such as tachistoscopic presentation, but it is one that is rarely noticed.

The research reported in this thesis is concerned with the way in which prior experience of the displayed word affects information processing in word recognition tasks. In word recognition we have a task in which success appears to depend on events of reception, and which is known to be highly dependent on the prior experience of the subject. But this does not justify the conclusion that input processing is developed by experience because it is possible that the responses change while the input properties to which they are given stay the same. The primary aim of the present research is to investigate the processes underlying the effects of prior experience in word recognition by the use of techniques that overcome this basic interpretive difficulty. In order to further clarify the nature of the facts, theories, and difficulties involved, the remainder of this chapter deals with three topics:

1. The scope of the effect of prior experience on word recognition.
2. The nature of the explanations which have been offered for these phenomena.
3. The nature of the problem of response bias in word recognition situations, and the attempts that have been made to overcome it.

The literature on each of these topics is very extensive, and the following sections do not attempt a comprehensive review. Instead they attempt to illustrate the major empirical findings and to show the various ways in which they have been interpreted.

## 1.1 <u>The dependence of word recognition on prior experience</u>

In the study of word recognition four areas of research have been predominant: these are the investigation of reaction time, the span of apprehension, reading efficiency, and recognition thresholds. In all four areas the prior experiences most relevant to performance are those in which the person met the words to be recognised. Many aspects of these prior experiences have been studied for their effect on word recognition: for example, their frequency, their recency, the modality through which the words were presented, their association with reinforcing events, and the emotional, motivational, and other meanings they develop for the words. Throughout this thesis the primary concern is with those aspects of prior experience that develop word identity. That is, with those aspects directly concerned with the presentation of the word itself, rather than those concerned with associated events, such as might develop meaning for the word. The effects due to these aspects of prior experience are normally called the effects of word familiarity. There are two main reasons for this emphasis. First, word identity must be established before meaning can be given to the word. Second, large performance changes have been shown to result from the prior experience of words, even if no meaning is given to them (Solomon and Postman, 1952).

Reaction time and reading efficiency are not of central concern to this thesis. They are therefore discussed only to the extent necessary to show their relation to the areas that are of more central concern and to show how general are the effects of familiarity.

### 1.1.1 Reaction time

Discrimination of verbal material was among the cerebral operations whose durations were estimated by the reaction-time method initiated by Donders in 1868. The methods and results are well illustrated by the experiments of J. McKeen Cattell (1886b).

His form of the method was to present a word, selected from a specified set of words, and to require the subject to make a reaction only if it was a particular one. Cattell determined the 'perception time' for this particular word by first subtracting from the average reaction time the simple reaction time, and then dividing the result by two. The division by two arose from the view that both perception and the subsequent preparation of the motor impulse were added to the simple reaction, and that these were of about equal duration. By such methods, Cattell determined his own 'perception time' to be 116 milliseconds for single letters, 141 miliseconds for short English words, and 150 milliseconds for short German words. (Cattell, as an assistant to Wundt, was probably well acquainted with the German language.) The calculation of 'perception time' may not be valid, but the fact remains that discriminative reaction time for a familiar word is little more than for a single letter, and for a familiar word in a native language shorter than for a familiar word in a foreign language.

Although discriminative, or choice, reaction time remained for some years a major tool in the study of word recognition and other perceptual processes (Woodworth, 1938) it is little used as a tool in contemporary word recognition research. The recent revival of interest in discriminative reaction time has been concerned with topics such as the relation of reaction time to the number of bits of information per stimulus presentation (Adams, 1964), rather than with the relation of reaction time to processes of word recognition.

### 1.1.2 The span of apprehension

Experiments on the span of apprehension are all characterized by the presentation of a visual display for a brief duration, and the subsequent calculation of the accuracy of the subject's reproduction. The resulting performance is variously known as the span of apprehension, the span of attention, and the span of perception. Many variations of the displayed material, the manner of reproduction, and the type of calculation have been used. Most have been examined for their dependence on prior experience, and the dependence is typically large. The span for randomly chosen letters is rarely above 7 letters; Zeitler and Becher in independent experiments, found that for familiar words 25 or 26 letters could be reproduced after a single brief exposure. Their experiments, and others showing similar results, are described by Tinker (1929).

If a sequence of words, syllables, or letters, is presented acoustically, rather than visually, the span calculated is known as the span of immediate memory. This too is known to be highly dependant on the familiarity of the presented material (Miller, 1956). At first sight it appears that this procedure is not related to word recognition. Nevertheless, both the span of apprehension and the span of immediate memory are related to word recognition in essentially the same way. In both cases the task of reproducing the word 'Bewegungsemfindungen', for instance, may be either one of immediate memory or one of word recognition. Which it is will, in this case, depend on the person's familiarity with German.

### 1.1.3 Reading efficiency

The familiarity of the material being read will clearly affect many aspects of reading efficiency. Some of the earliest measurements are reported by Cattell. He says:

> I find it takes about twice as long to read (aloud, as fast as possible) words which have no connexion as words which make sentences, and letters which have no connexion as letters which make words. When the words make sentences and the letters words, not only do the processes of seeing and naming overlap, but by one mental effort the subject can recognise a whole group of words or letters, and by one will-act choose the motions to be made in naming them, so that the rate at which the words and letters are read is really only limited by the maximum rapidity at which the speech-organs can be moved....When a passage is read aloud at a normal rate, about the same time is taken for each word as when words having no connexion are read as fast as possible. The rate at which a person reads a foreign language is proportional to his familiarity with the language. For example, when reading as fast as possible the writer's rate was, English 138, French 167, German 250, Italian 327, Latin 434, and Greek 484; the figures giving the thousandths of a second taken to read each word. Experiments made on others strikingly confirm these results. (Cattell, 1886a, p.64-65.)

Morton (1964) shows that as the order of approximation to English of the material increases, reading speed increases, the eye-voice span increases, the mean number of fixations and regressions decrease and the number of errors decreases. The degree of approximation to English, however, did not affect the mean fixation time. Similar results were obtained by Sumby and Pollack (1954).

### 1.1.4 Word recognition threshold

In all the variety of recognition threshold measures there are two common elements. These are the systematic variation of a stimulus parameter affecting accuracy of recognition, in accordance with the ascending method of limits, and the definition of the threshold as that value of the stimulus parameter at which reproduction of a specified degree of accuracy occurs. In nearly all experiments the words are presented either visually or acoustically. Numerous parameters of the visual stimulus have been used; duration, brightness, distance, the amount of blurring, the number of onion skin papers through which the subject sees the word, and many others. The parameters of the acoustic stimuli on which research has concentrated are intensity, and the relative amount of background noise. The aspects of prior experience whose effects on the recognition thresholds have been studied are also numerous, including: the frequency of experimental presentation of the word, the modality of presentation, the relative frequency with which the word occurs in popular magazines, and the emotional, motivational, or neutral meanings that have been associated with the word. Most combinations of type of threshold measure and type of prior experience have been studied. Brown (1961) gives a thorough account of the results. The experiment of Solomon and Postman (1952) has served as a paradigm for many later experiments. They showed that the visual duration threshold for word recognition is a sharply negatively accelerated decay function of experimentally controlled rehearsal frequency. This was proved to be a reliable phenomenon by the replication of King-Ellison and Jenkins (1954). Similar results were obtained for the visual brightness threshold by Baker and Feldman (1956) and for auditory masking thresholds by Postman and Rosenzweig (1956).

The general outcome of this research is that any prior experience with initially unfamiliar words will affect the recognition thresholds for those words, no matter which of the methods for measuring the recognition threshold is used. There are two reported exceptions to this generalization. First, Postman and Conger (1954) report that frequency of exposure when uncorrelated with response frequency does not influence the visual duration thresholds. Sprague (1959), however, reports that it does. The difference is very probably due to the fact that in Postman and Conger's experiment, the prior presentation of the words was as parts of other words, whereas in Sprague's experiment they were presented as words in their own right. If so, this increases the importance of word identity as an aspect mediating rehearsal effects. Second, Postman and Rosenzweig (1956) find no effect of acoustic presentation on the visual duration threshold. However, Forrest (1957) and Weissman and Crockett (1957) do report such an effect. Whether there are exceptions or not, the effect of prior experience on recognition thresholds is clearly a phenomenon of very great generality.

### 1.1.5 Summary

Four different performance measures have been considered; reaction time, span of apprehension, reading speed, and recognition threshold. In all four the subject's basic task is to determine the nature of the word or words in the visual display, and in all four the performance depends on the speed with which he does this. In all four, also, it has been found that performance is better if the words are familiar to the subject. These common effects need not all be due to the same cause. Indeed the phenomena in the four areas are most often investigated and explained independently. Nevertheless, it seems unwise to reject the search for a common explanation, until there are good grounds for doing so.

## 1.2 Some proposed explanations

Explanations of the effect of prior experience on word recognition are commonly divided into two groups. In simple terms, the first group states that the effect occurs because, with familiar words, the subject sees more of the presented stimulus; and the second group states that it occurs because, with familiar words, the subject's guesses are more likely to be right. The issue between the two groups is widely debated, but it is described in a most informal way. It is variously stated, for example, as perception versus response, seeing versus saying, and stimulus discriminability versus response bias. Unfortunately the use of terms of this kind confuses two issues. First, there is the issue regarding the amount of stimulus information that controls word recognition performance. That is, does a greater amount of the stimulus control performance when the word is familiar, or does the amount of stimulus information used remain unchanged but become more accurately supplemented by the subject? Second, there is the issue regarding the visual perceptions of which the subject is aware. That is, is the subject aware of different visual perceptions when the word is familiar, or are unchanged visual perceptions reported by the subject in a different way? Although very commonly confused, these issues are clearly distinct. The second can only be resolved when techniques are discovered that will allow the investigation of a subject's awareness other than through his verbal report. No such techniques are available at present, and it is therefore with the first issue that this thesis is primarily concerned.

To avoid the ambiguity inherent in the terms commonly used, and to make it clear that only the first issue is being referred to, explanations will be divided according as to whether they offer explanations in terms of input processing or in terms of supplementation. Explanations in terms of input processing postulate that, as a result of changes in the way the input is processed when words are familiar, more information from the stimulus is transmitted into the word recognition response. Explanations in terms of supplementation postulate that performance changes are due only to the increased accuracy of that component of word recognition performance which is determined by variables extraneous to the presented stimulus. In this thesis that part of word recognition performance which is due to the stimulus will be called the stimulus component, and the remainder, which must therefore be supplied by the subject himself, will be called the supplementary component. Thus, explanations in terms of input processing claim that familiarity affects the stimulus component, and explanations in terms of supplementation claim that it affects the supplementary component. An attempt to clarify further the meanings of these terms will be made in Chapter 3.

### 1.2.1 Explanations in terms of input processing

The early workers took it for granted that the phenomena were due to a change in input processing. Cattell's explanation was in terms of the person seeing the word as a whole. He said:

> We now come to consider the time it takes to see a word, a process with which the brain is constantly occupied. Twenty-six words were taken, and when the expected one was seen the observer lifted his hand. The perception-time so determined is the time needed to distinguish the word from the other twenty-five; the time is slightly longer when it is necessary to distinguish words from others very similar in form ; for example, hand from band. Indeed we must remember that perception is not a sharply defined process. As I have shown, we see a letter before we see what letter it is; in like manner a further time passes before we see the letter in all its details, that it is not perfectly printed, for example....It will be noticed that the perception-time is only slightly longer for a word than for a single letter; we do not therefore perceive separately the letters of which a word is composed, but the word as a whole. (Cattell, 1886b, p.387.)

Cattell gives a similar view in the statement quoted in Section 1.1.3. He seems not to have noticed the possibility that the letters could be perceived concurrently but separately. Nor does Woodworth, who endorsed Cattell's view and expanded on it:

> One curious fact noted by several investigators... is that even when O can report but a few, he believes he has seen all the letters distinctly during the actual exposure. Unless they formed a familiar word, he forgot them before reaching them in his report. Nothing is more likely; unless some word suggested itself at once, brute memory would not hold all the disconnected letters. But if O is not mistaken in this impression, he gets for an instant perfectly adequate cues of a correctly presented word. If for an instant he sees the whole word clearly, as he thinks he does, he has all the cues he could desire....The most effective cue for

> reading a long word consists of a large share of the letters in the word, seen with fair distinctness for an instant.
>
> This conclusion does not mean in the least that the word is read by spelling it out; evidence previously cited is enough to exclude that supposition. What the conclusion means is that an adequate simultaneous view of the entire word is the cue for recalling the word. (Woodworth, 1938, p.742-743.)

Most of the early work on word recognition was concerned with the determination of those aspects of the word which served as cues for its recognition. Erdmann and Dodge (Tinker, 1929) agreed with Cattell that familiarity caused a change in the cues used, but proposed that it was not the whole of the word which served as the cue for familiar words, but only its general or external outline. Goldscheider and Muller (Tinker, 1929) emphasised the importance of particular letters, which they called 'determining letters', in forming this general outline. It was assumed that whole word form or general outline cues could not be used with unfamiliar words, the subject having then to revert to the more laborious procedure of identifying the word letter by letter. Tinker accepts the view that familiarity changes input processing. He suggests this may take the form of a 'natural tendency to combine the different elements of a visual impression into higher perceptual units whenever grouping is possible'. (Tinker, 1929, p.227). These explanations were primarily concerned with reaction time, the span of attention, and reading, but were applied to some thresholds, e.g. distance thresholds, and could easily be extended to most of the others. With respect to reading the general view was that the subject read by letter, word, or phrase, according to his purposes and his familiarity with the material.

The idea that the phenomena might not involve improved input processing, but be due only to improved efficiency of supplementation, either did not occur to most of these investigators or did not strike them as a critical difficulty. The explanations they offer are suggestive, but lack crucial details. For instance, it is difficult to determine what 'perceiving the word as a whole' means. It might mean perceiving each of the letters concurrently, although Cattell's statement seems to imply that he means something else. What this is, and what processes may achieve the perception of words as wholes, neither he nor Woodworth suggest .

Few modern writers offer explanation emphasizing input processes, and those that do give little detail. Portnoy, Portnoy, and Salzinger (1964) suggest it is a matter of 'heightened stimulus discriminability', but give no more detail of what this entails. Neisser (1954) reports an ingenious demonstration which indicated that prior experience may exert its influence through a 'perceptual process' or seeing, rather than through 'verbal response' or saying; but no further analysis of this distinction is offered.

### 1.2.2 Explanations in terms of supplementation

Although ignored by many workers the importance of supplementary processes was pointed out from the time of the earliest experiments. Zeitler in 1900 and Winch in 1925, as described by Tinker (1929), were claiming that only part of the word served as a cue to recognition, the rest being filled out by association. The parts thought most likely to serve as cues were the 'dominant letters', that is, the ascenders, descenders, and capitals.

Since about 1950 explanations in terms of supplementation have been given a great deal of attention, and are now widely accepted. These explanations take many forms which differ amongst themselves in important ways: firstly, in the nature of the supplementary processes that they postulate; and secondly, in the way stimulus and supplementary components are presumed to combine to produce the overall recognition performance.

Supplementation explanations are often said to be of two types: those claiming that stimulus and supplementary components combine to form particular recognitions, and those claiming that they do not. Kempler and Wiener (1963) call the first type part-cue response-characteristic theories, because they claim that experimentally or motivationally induced differences in recognition performance result from differential response characteristics to the seen part-cues. The second type of supplementation explanation is one which denies part-cues and claims that the stimulus component is either all or nothing. If this claim were true supplementation would occur only in the complete absence of any stimulus component. Supplementation explanations of this type can thus be described as no-cue response-characteristic theories, or simply as no-cue theories.

Contrary to common belief the no-cue theories - which are at best false and at worst absurd - have no supporters. The explanations to be reviewed in this section are therefore all part-cue theories. As, however, it is the no-cue theories which are the most commonly attacked, an attempt to show that they have no supporters must first be made.

Two different forms of the no-cue theory have been discussed in the literature. The first form is that which denies the stimulus any role in recognition performance. Kempler and Wiener, for instance, suggest that Goldstein may support this view. They say:

> It is not clear from the various expositions of the response explanations whether any or how much variance in threshold behaviour can be attributed to stimulus input. Occasionally the impression is even given that response probabilities remain constant despite changes in stimulus information. For example, Goldstein (1962) states: 'The results indicate that the subject does enter the perceptual situation with clearly defined response habits which are not under the control of the perceptual stimulus and which can influence the subject's recognition score' (p.27). (Kempler and Wiener, 1963, p.350.)

However, if Goldstein is quoted at greater length it is clear that he does not claim recognition scores to be independent of stimulus information:

> The present study represents an attempt to isolate two sources of variance in perceptual recognition scores: variance related to highly overlearned response habits and variance related to the presence of a visual stimulus. The results indicated that S does enter the perceptual situation with clearly defined response habits which are not under the control of the perceptual stimulus and which can influence S's recognition score. With regard to the perceptual defense effect words classified as anxiety arousing have less probability of being used as recognition guesses and this negative response bias makes a correct signal detection less likely when a discriminative stimulus is presented. (Goldstein, 1962, p.27.)

The second form of no-cue theory admits that there are both stimulus and supplementary components of recognition performance, but supposes that they occur only on different trials. Although not explicit on this matter, Brown and Rubenstein (1961) seem to take this to be the most general form of response bias theory, and they suggest, as do many other writers, that Goldiamond and Hawkins support such a theory. Goldiamond and Hawkins (1958) demonstrated that a logarithmic relation between word frequency and pseudo-recognition thresholds could be obtained without stimulus words and thus without a stimulus component of recognition performance. It is clear, however, that they do not propose a no-cue theory of any kind to account for performance when stimulus words are presented. They make the assumption that when words are perceptible then they are all equally perceptible regardless of the frequency with which they have been previously met. This implies that partial stimulus control of word recognition may occur. Goldiamond, in another article, is more explicit. He says:

> The organism enters the perception situation with built-in response biases, that is, he has been shaped by preceding conditionings. Certain of these biases are so regular as to enable us to recognize him by them; presumably personality relates to such biases....
>
> The effect of the interaction of this factor with partial identification of a discriminated stimulus needs little elaboration. A couple of letters discriminated may provide the occasion for a response which has been previously reinforced under similar conditions. If this response has a higher probability than others, and this bias will lead to quick congruence, S will display sensitization effects. (Goldiamond, 1958, p.397-398.)

This account shows all the basic characteristics of a part-cue theory.

(Primarily, the experiment of Goldiamond and Hawkins should be seen as demonstrating a weakness in the traditional methods of threshold measurement. Initial presentation must be below threshold. If the steps by which the presentation energy is raised are small, pseudo-recognition thresholds will result; whereas if they are large, threshold measures will be crude. The existence of an acceptable size of step will depend upon specific conditions, particularly upon the subject's knowledge of which words are to be presented, and on the degree to which these are restricted by the part-cues available at short durations.)

All explanations in terms of supplementation are therefore part-cue theories. Those described here have been chosen either because they are widely influential, or because they demonstrate key features clearly. No attempt is made to give a comprehensive review of all supplementation explanations.

The statement by Howes (1954) of one well known explanation is sufficiently detailed and clear to deserve full quotation:

> The interpretation to be considered here can be characterized as a response-emission theory. We may think of the momentary probability of a word (defined as the strength of S's tendency to emit that word in preference to any other) as a quantity that fluctuates widely from moment to moment in accordance with changes in innumerable environmental and organismic conditions that affect the emissions of words. Over a time period of considerable length the average of these momentary probabilities will be a relatively stable statistic, which we shall call the base probability of the word.
>
> Visual exposure of a word to S for a brief length of time $\Delta t$ is assumed to represent an environmental event tending to cause emission of the exposed word. The momentary probability of a word following its exposure may therefore be analyzed into two components: a component due to the ordinary impulses to emission of the word,

> whose average value is the base probability; and a component due to the additional impulse of the word's visual exposure. Consequently, the average probability of a word following each of a number of exposures of given duration must be greater than the corresponding average base probability of the word. A given level of probability following exposure can result either from a relatively large component due to base probability plus a small additional component due to exposure or from a relatively small component due to base probability plus a large additional component due to exposure. It follows that the duration threshold of a word, which is defined as the duration of exposure for which 50% of S's reports following exposure are correct, will be lower for a word with high base probability than for a word with low base probability. (Howes 1954, p.106.)

There are grave weaknesses in the notion of base probability suggested by Howes. As the base probability is estimated over all situations, it already includes emission probability in situations where words are viewed briefly. The two probabilities are therefore not independent. Another difficulty is that base probabilities are extremely small; as estimated by the Thorndike-Lorge word count most words have a base probability of less than .0001. On the formulation of Howes, therefore, accurate word recognition would be so largely controlled by the component dependent on visual exposure that variations in threshold due to varying word frequency would be extremely small. They are in fact very large. Finally, the gravest weakness is that the base probability is a false estimate of prior frequency of emission when applied to any particular situation or limited class of situations, such as threshold measurement experiments. Changes in emission probabilities across different situations are large and discontinuous. In experiments like those of Solomon and Postman (1952) and Goldiamond and Hawkins (1958), for example, no English words are emitted at all.

The conception of word recognition as determined by diverse factors, implies that these factors may often be in competition, and there are explanations of the effects of prior experience on recognition which emphasize this aspect. One of the first was the hypotheses-theory of Bruner and Postman (Allport, 1955). They talk of the strength of perceptual-hypotheses instead of the strengths of tendencies to emit a word. Hypothesis strength is said to be dependent on the frequency of past confirmation, the number of alternative hypotheses available, motivational support, and cognitive support. If the strength of a perceptual hypothesis is increased, less information is required to confirm it, and more information is required to infirm it. Which of a number of competing hypotheses is confirmed will depend upon their relative strengths and upon the stimulus information available.

Solomon and Postman take a similar line. They state the position clearly:

Given a population of associations, the one which has been exercised most frequently will have the greatest probability of being elicited relative to other, like associations. How will this fact influence S's responses in a tachistoscopic situation? When a stimulus pattern is presented at short durations or at low illumination intensities, only fragments of the total word stimulus are 'effective'. Such a stimulus fragment may be considered to represent a point on the generalization dimension of stimulus patterns capable of eliciting the correct verbal response. A given stimulus fragment may, of course, be located on several generalization dimensions, each involving a different word. Which verbal response will be given depends on the relative strengths of association which have been established, through generalization, between the particular stimulus fragment and the different response words. If the visually presented stimulus word has had a greater frequency of prior usage than any of the competing response words, a correct response is highly probable.

Words of lower prior exercise frequency will be interfered with by words of higher exercise frequency. This interference will manifest itself in the tendency of S's 'guesses' to be high frequency words. If the actual stimulus word is a low frequency word, effective stimulus fragments will elicit erroneous 'guesses' until the amount of effective stimulation becomes great enough on successive exposures to reduce the number of competing word responses. One may describe the increase in effective stimulation as limiting the range of competing 'hypotheses' (1, 10) or one may speak of a restriction of stimulus generalization. In this connection it is interesting to point to the parallel between overt intrusions in retroaction and proaction experiments and wrong pre-recognition responses in the tachistoscopic situation. In

> both cases, a strong competing response temporarily replaces the correct response. (Solomon and Postman, 1952, p.597.)

This reasoning has been developed by Havens and Foote (1963). They report that the thresholds for short English words are determined by the number of English words having a similar structure, and a high frequency, but not by the frequency of the word itself. They conclude that it is only competition which determines thresholds, and that the low thresholds for high frequency words is to be explained on the basis of their having low frequency competitors. High frequency words, they suggest, will have low frequency competitors as they themselves already occupy the high frequency slot for words of that configuration. The weakness in this argument is that word configurations are not found randomly distributed throughout the frequency range; on the contrary, configuration is highly related to frequency. High frequency words, for instance, tend to be short words. A high frequency word is thus more likely to have a high frequency than a low frequency competitor. If this argument is correct, then a word's own frequency must be important in determining its interaction with competitors, otherwise high frequency words would have the highest thresholds, as it is they which face the strongest competition.

Lastly, a few weaknesses common to all supplementation explanations will be mentioned:

1. They are limited to span of apprehension and to threshold phenomena. They have been formulated to explain the increased accuracy with which a subject reproduces familiar words. Reaction-time and reading speed depend upon the rate at which the person recognizes words without making errors. Accuracy is not a variable. As supplementation explanations say nothing about the rate at which supplementation occurs, and as they usually imply the occurrence of errors, they are not relevant to measures of either reaction time or reading speed.

2. Explanations in terms of the response-characteristics to part-cues should state what the part-cues are, but they rarely do. This has the result of making them hard to test, as will be seen more clearly in the next chapter.

3. Recognition is often seen as response emission, or as tendencies to response emission, where the response closely corresponds to the stimulus (e.g. Howes, 1954). On the face of it, this is a surprisingly perverse assumption. If it were correct, recognition of the sound of a jet engine, or of a painting would be hardly possible. In any case, recognition seems to be necessary for the

person to know which response to tend to emit. In view of such difficulties, adoption of this assumption would be expected to result only from very strong evidence in its support. No such evidence seems to exist. It is worth noting that there is no necessity for supplementation explanations to be in response terms, and a few are not; hypothesis theory for example.

4. Working with the span of attention, Goldscheider and Muller, as reported by Tinker (1929), discovered that for straight and curved lines in unrelated arrangements, about four strokes could be described and reproduced. But letters are made out of such strokes, and a long word could certainly not be reconstructed from just four of them. (It may be that more strokes are recognized if they form letters, but to claim that this is so is to admit the effect of prior experience on the stimulus component.) Consequently, the extent to which accuracy is increased by prior experience, appears far too large to be due to supplementation.

It can be seen that input processing and supplementation explanations are very different. If it is the case (as claimed later in this thesis) that some effects of prior experience are mediated by the stimulus component, and some by the supplementary component, then any attempt to explain overall performance changes in terms of either input processing or supplementation is bound to arrive at a false account. Separation of the stimulus and supplementary components of performance is thus essential if our understanding of the effects of prior experience on word recognition is to advance.

## 1.3 The separation of stimulus and supplementary components

This section will give an account of the attempts that have been made to determine how the effects of prior experience are distributed between the stimulus and supplementary components. In view of the importance of the problem it is not surprising that many attempts at resolution have been made. However, no generally accepted solution has yet been offered, as is attested by frequent statements to that effect (e.g. Gibson, 1963; Postman, 1963), and by the fact that new attempts are continually appearing.

It is generally believed that separation of stimulus and supplementary components will result from resolution of the problem of response bias. That is, from control for the different *a priori* probabilities associated with different recognition responses. It is therefore the problem of response bias that most workers have tried to solve. However, it will become apparent that the problem is essentially not one of response bias but one of stimulus bias.

Experiments designed to test response bias explanations by showing that either correct or false recognitions depend upon the stimulus presented test only no-cue theories. They therefore test the weakest kind of supplementation explanation, which no one appears to hold. In any case, demonstration of the obvious fact that there is stimulus control of recognition in no way solves the issue as to whether stimulus control varies with prior experience.

The remaining attempts to decide between input processing and supplementation explanations fall into five groups: those presenting stimuli in such a fashion that the part-cues available to the subject are known; those using phenomenal reports; those testing hypotheses derived from explanations in terms of either response biases or other forms of supplementation; those measuring response biases and thresholds concurrently; and finally, those using indicator responses other than reproduction of the words being recognized.

### 1.3.1 Part-cue control

The rationale of this approach is given in the following argument. Reproduction has two components, the stimulus and the supplementary, which are not separable under marginal conditions of presentation. It is therefore impossible to know how changes in reproduction accuracy are divided between them. If presentation is not marginal, however, separation will be possible as the stimulus component will be known. Thus, when partial cues are presented above threshold, the way in which the subject supplements them can be studied. An approach of this kind is suggested by Kempler and Wiener (1963). The experiment of Goldiamond and Hawkins (1958), already mentioned, can be seen as an early form of this approach. If no stimulus is presented, there is no stimulus component, and any change in performance must be due to a change in the supplementary component.

The first difficulty with this procedure is that response characteristics in the total absence of cues will not be the same as those in the presence of part-cues, and part-cues are normally available in tachistoscopic situations (Bricker and Chapanis, 1953). Spence (1963), therefore, sought to demonstrate that the response biases to part-cues were also such as could account for the effect of prior experience on thresholds. Her experiment shows the major characteristics of this approach. English words of four letters were presented to subjects according to normal threshold measurement procedures. Three letters of each word were heavily typed, so that they would serve as part-cues. To make the fourth letter effectively absent, it was either typed lightly, so that it was barely visible under normal viewing conditions, or replaced by a smudge. The words were chosen so that the fourth letter could be filled in with either of two, and only two, letters; one forming a high frequency word and the other a low frequency word. The results showed that guesses of the fourth letter were much more likely to make high familiarity than low familiarity completions. Other experiments in a similar vein are those of Kempler and Wiener (1964), Goldstein (1962), and Smock and Kanfer (1961).

These experiments make a useful contribution, for they show the variables on which the supplementation of part-cues depends. They leave little doubt that in cases where a person can only use part-cues, performance will depend on response biases. Such cases undoubtedly arise, and so the dependence of word recognition on prior experience is at least in part a matter of supplementation. But this is no resolution of the problem, for the issue is whether performance change under marginal conditions is due to changes in input processing, in supplementation, or in both. In essence, these experiments show that performance change is a matter of response bias in cases where it could not possibly be a matter of perception, but leave untouched the question of whether it is perception in cases where it could be. In other words, it is impossible to show that a person fails to see a letter when it is present by showing that he can guess it when it is not.

One other aspect of Spence's experiment must be mentioned. It is that 'thresholds' were measured by treating the fourth letter as present. This procedure faces the obstacle that it is not possible to tell to what extent the thresholds were pseudo-thresholds. Spence does not say whether the lightly typed letters were at all visible under conditions of brief presentation. Even if they were, interpretation of the thresholds would be difficult, for with only two possible completions, accurate responses can easily occur independently of information from the input. (This is the weakness of traditional threshold measures noted in Section 1.2.2.) The combination of clear part-cues with unclear parts was probably used to avoid the subject reporting three letters and a gap. Unfortunately, it complicates interpretation of the results. Any variation in recognition of the unclear parts, as a function of the available part-cues, is just another demonstration of the dependence of recognition on context; it still suffers from the familiar ambiguity. That is, if the fourth letters in Spence's experiment were at all visible under tachistoscopic presentation, it cannot be known whether they were recognized better in highly familiar words because of better input processing, or because of better supplementation.

### 1.3.2 Phenomenal reports

The most natural and straightforward way to state the issue is by using the words 'seeing' and 'saying', and this is how it is commonly put. Some workers suggest that, if this is the issue, it might be resolved by simply asking the subject to report only what he sees. This technique for response bias control is used by Haber (1965) and by Morton (1964). Haber concludes that word frequency effects are mediated by response processes (although the stimulus controls more basic perceptual processes). Morton concludes that context and frequency effects are mediated by perceptual changes.

Assessment of the role of phenomenal reports will centre on two main aspects; the relation of perceptual awareness to input processing and supplementation, and the relation of report to awareness. Perceptual awareness is commonly identified with the information the person in fact received from the stimulus, so that if a person 'sees' more of a familiar stimulus, then input processing must be more efficient. This is the view Haber seems to favour. Morton, on the other hand, holds the view that awareness is of the combined result of input processing and supplementation. In this, he agrees with the hypothesis theory of Bruner and Postman. It is reasonably clear that awareness is not a faithful representation of the information received from the stimulus. Firstly, the subject claims awareness of elements not in the stimulus, as indicated by the errors of subjects who claim not to be guessing. Secondly, experiments carried out in association with the research reported in this thesis indicate that the reproduced letters said by the subject to be guessed and not seen, are in some conditions more accurate than is possible by chance.

As an attempt to separate stimulus and supplementary components, therefore, the introspective method proceeds by asking the subject to make the separation himself, but fails because with marginal presentations he does not know which is which.

Furthermore, even if the subject could make the separation this would not solve the problem, for the only way to determine whether he could would be to compare his separation with the stimulus and supplementary components. If this was possible the problem would already be solved.

As an attempt to determine whether perceptual awareness changes with prior experience independently of the input versus supplementation issue, this approach faces the old but real problem of the relation of awareness and report. This problem is particularly important where the perceptual awareness being considered exists only briefly. An experiment of Glanville and Dallenbach (1929) is of importance here. They report that the span of apprehension is not the number of items to which a person is aware of attending, but the number he does not forget. Their evidence for this is that items are reported as all appearing equally clear during presentation, although only a small proportion of them can be accurately reported. This wide field of distinct vision is well documented, and consequently it does not appear possible to accept the view that what is reported is what is 'seen'. The report certainly does have some relation to portions of the stream of consciousness, but present techniques allow no clear decision as to what these portions and relations are.

1.3.3 Theoretical development and test

In this approach, theories are developed on the basis of either an input processing or supplementation interpretation, and their consequences tested. For instance, Zajonc and Nieuwenhuyse (1964), assumed that the frequency effect was due to response bias, and noted that the S-R drive theory developed by Spence (1956) states that an increase in drive raises the probability of responses governed by strong habits, and lowers the probability of responses governed by weak habits. On this basis an increase in drive should heighten the effect of frequency on recognition thresholds. The results obtained by Zajonc and Nieuwenhusye showed no significant frequency-drive interaction, so they concluded that response bias plays a negligible role in threshold effects. A minor objection to such a conclusion is that, statistically, little weight can be placed on a failure to find an effect, particularly in instances where the theory being tested makes no prediction about the size of the effect. A more important objection is that, as innumerable theories involving the notion of supplementation could be developed, tests of particular ones do not necessarily test the others. The value of any particular test depends on the degree to which the prediction concerned is common to supplementation explanations in general. For instance, prediction of an interaction between drive and the frequency effect, may be common to some supplementation explanations, but it certainly is not common to all. The premise, basic to all supplementation explanations, is the statement that the prior experience changes only the supplementary component. It is this statement, or those it implies, which must be tested; not the theories which may be built around it.

### 1.3.4 Measures of response characteristics

If variations in thresholds are due to the different probabilities associated with the different indicator responses, then simultaneous measures of thresholds and of response probability should show them to co-vary, e.g. response probability should depend on frequency in the same way as thresholds. This technique has been used most in studies of perceptual defence (Mathews and Wertheimer, 1958; Minard, 1965). Neisser's attempt to determine whether set affects 'perceptual process' or 'verbal response' is a form of this technique (Neisser, 1954). He showed subjects a list of 10 English words and told them these would be included in the words to be displayed briefly in the tachistoscope. Thresholds for the set words were found to be lower than those for control words. Thresholds for homophones of the set words were not different from those of the control words. Neisser concludes that as homophones are reproduced by identical responses, the effect of set could not have been mediated by changes in response frequency. In the experiments of Mathews and Wertheimer, and of Minard, the bias for or against responding with emotional words was estimated by the frequency with which emotional words were given as erroneous responses, to blanks or to other words. Both experiments produced results indicating that the bias against responding in error with emotional words was not large enough to account for the difference in the recognition of emotional and neutral words.

The basic weakness of this approach is that it only tests the no-cue theory, which is clearly invalid as a general explanation anyway. A part-cue theory, can easily explain the results of these experiments. In Neisser's experiment, for instance, one pair of homophones was 'COLONEL' and 'KERNEL'. The set established by the instructions could increase the probability of correctly completing the part-cue 'COL----' without affecting the manner in which the part-cue 'KER---' is completed. The effect of set in Neisser's experiment could therefore be explained as mediated solely by the supplementary component without this explanation predicting any changes in the thresholds for homophones. On the other hand, the effect could equally well be explained as mediated solely by the stimulus component, and so the ambiguity remains.

In view of these considerations it can be seen that the response-characteristics which must be measured are those to the part-cues the subject uses. But to determine what part-cues are used is the very problem with which we began. This difficulty is increased by the fact that experiments using the above approach are typically based on some notion of response probability in the abstract, and display blanks or haphazardly chosen words to measure it. If the stimuli used to measure response bias were similar to those for which thresholds were measured, the part-cues used in both instances would be more likely to be similar. Even then, however, results would be suggestive rather than conclusive.

### 1.3.5 Forced-choice techniques

This is the solution in which perhaps most hope has been placed. It is developed from the study of psychophysical methods made by Blackwell (1953). The proposal made is that as different indicator responses have different probabilities of emission, quite apart from recognition, the problem might be resolved by using the same indicator responses for all acts of recognition. The most common procedure is for the subject to indicate in which of four quadrants a selected stimulus is located. Experiments using techniques of this kind to control response bias are those of Goldstein and Ratleff (1961), Portnoy, Portnoy, and Salzinger (1964), and Taylor, Rosenfeldt, and Schulz (1961). The basic inadequacy of the method, however, is clearly seen by Taylor, et al.; their discussion is sufficiently clear and pertinant to warrant quotation:

> The forced-choice technique would appear to overcome Goldiamond's methodological criticisms of the method of limits. In the present investigation evidence was obtained that indicated that word frequency is related to verbal report even when response bias is controlled.

> The survival of the empirical relationship between performance and prior frequency of usage with still another source of extraneous variance reduced or eliminated may give added confidence to the perceptual interpretation. But even in the forced-choice situation S is still perceiving partial cues and guessing as to the spatial location of the designated stimulus. Thus the question remains unanswered as to whether perception is influenced by frequency of prior usage or whether fewer partial cues are needed to identify more familiar materials.
>
> Whatever the psychophysical method, partial perception would seem to be inevitable if complex patterns are to be employed. The search for a 'pure' measure of perception would thus appear to be a futile one. The latter conclusion is hardly novel. (Taylor, Rosenfeldt and Schulz, 1961, p.494-495.)

From this discussion it can be seen why attempts to decide between input processing and supplementation explanations have not succeeded. The problem is not primarily one of response probabilities at all. If a person's prior experience changes the efficiency with which he can replace lost or absent information, then this changed efficiency can affect recognition performance no matter what the particular indicator response may be. The difficulty is due, not to the presence of response biases, but to the presence of conditional dependencies between the letters of the words presented. That is, to the presence of what could be called stimulus biases. A person's prior experience can only affect his ability to replace lost information if there are biases in the selection of stimulus words. If the stimuli are selected in an unbiased fashion, supplementary and stimulus components can be separated, independently of whether there are response biases or not. Exactly how this can be done will be shown in Chapter 3. First, an experiment is reported which tests some predictions of the supplementation explanations reviewed in Section 1.2.

# CHAPTER 2

## EXPERIMENT 1: RECOGNITION THRESHOLDS, REJECTION THRESHOLDS, AND USAGE FREQUENCY

When a distinction is excessively difficult to make empirically, the suspicion must arise that it is an empirically meaningless one generated solely by the vagaries of language. The distinction between perceptual and response processes in word recognition may warrant this suspicion, particularly while stated in such terms. Later chapters attempt to show that so unproductive an end to the affair can be avoided. An indication of how this may be done is provided by the results of the investigation reported in this chapter.

Input processing and supplementation explanations differ most in their predictions regarding the occurrence of the learned word as an incorrect response, but research has concentrated on the occurrence of the learned word as a correct response. Both explanations predict that the subject is more likely to give a correct response when familiar words are presented. Where their predictions differ is with respect to what will happen when other words are presented. Explanations in terms of supplementation predict that, in addition to being given more often correctly, the familiar words will be given more often incorrectly, when the words presented are similar to the familiar words. They also predict that although learning makes the recognition of the familiar words easier, it will make the recognition of similar words harder. These implications can be clearly seen in the explanation of Solomon and Postman quoted in section 1.2.2. In contrast, explanations in terms of input processing carry neither of these implications.

The above considerations indicate the need for a direct investigation of the effects of prior learning on recognition when the words presented are not the learned words but are similar to them. This chapter reports such an investigation. Subjects rehearsed Turkish words, to various frequencies. Rehearsal frequencies were then related to the recognition response given to similar words as well as to the learned words themselves. Rejection thresholds were measured in addition to the usual recognition thresholds. The rejection threshold is defined as the longest exposure duration at which the word is given as an incorrect response to the presentation of another word. Three predictions were tested:

1. The recognition thresholds for unrehearsed words increase with the rehearsal frequency of their competitors. (Competitors are words of similar structure to those presented.) This prediction is made explicitly by Havens and Foote (1963), but appears to be an implication of all currently held supplementation explanations.

2. The probability that a word will occur as an incorrect response to similar words increases with its rehearsal frequency. This is clearly

an implication of all currently held supplementation explanations.

3. Rejection thresholds, for words occuring as incorrect responses, increase with the rehearsal frequencies of those words. Although rejection thresholds have not been previously measured, they are clearly relevant to theories in which ease of confirmation and resistance to infirmation are claimed to depend on a common property. In the formulation of Bruner (1951), which is supported by Allport (1955) and also by Blake and Vanderplaas (1950-1951), this common property is 'hypotheses strength'. In the formulation of Solomon and Postman (1952), as developed by Havens and Foote (1963), the common property is the 'competitive strength of responses'. Both formulations imply that rejection thresholds mirror recognition thresholds. If this is the case rejection thresholds will be a sharply negatively accelerated increasing function of rehearsal frequency.

None of these predictions appear to have been directly tested by the use of experimentally controlled rehearsal frequency.

The experiment was designed to allow investigation of two further aspects:

1. The effect of rehearsal frequency on the recognition thresholds for the rehearsed words

themselves. This was expected to replicate the effect found by Solomon and Postman, and to provide a basis against which to compare rejection thresholds.

2. The number of presentations intervening between rejection of the learned competitor and correct recognition. Theories in terms of competition predict that, as correct recognition depends upon overcoming competition, it will occur at the same time as the strongest competing response is rejected (see, for example, the quotation from Solomon and Postman, given in Section 1.2.2.).

## 2.1 Method

The experiment consisted of two phases: the rehearsal phase, in which the subject rehearsed words to selected frequencies; and the measurement phase, in which thresholds were measured. In the rehearsal phase, Turkish words of seven letters were presented in a tachistoscope; each word remained on the screen for four seconds, with an interval of eight seconds between words. During each interval the subject spelt the preceeding word letter by letter, and then pronounced it as though it were a word in English. In this series, words recurred at varying frequencies, such that two words occurred at each of the five frequencies: 1, 2, 5, 10, 25. These will be called the rehearsed words. Fourteen other words occurred once each and were not used again. The 100 presentations so required were given a random order, with a new randomization for each subject.

After a break of about ten minutes, thresholds were measured for three groups of words: the ten rehearsed words; ten matched words not previously seen by the subject (these were constructed by changing two letters of each rehearsed word); and ten control words not previously seen by the subject, and having no particular similarity to the rehearsed or matched words. The order in which the thresholds for these 30 words were measured was randomized except that exactly half of the rehearsed words occurred before their corresponding matched word. A new randomization was made for each subject.

At the commencement of the measurement phase the subjects were informed that some of the words they were to see were words they had previously rehearsed, and that some of them would be words they had never seen before. Threshold measurement began with a display duration of 40 milliseconds. This duration was increased by ten milliseconds steps to 200 milliseconds, and thereafter by steps of 20 and 30 milliseconds. The subject was encouraged to report as much as possible of the word after each presentation, and all recognition responses were tape-recorded. The sequence was ended after the subject had given three correct responses in succession. Two recognition threshold measures were recorded: the duration at which the first correct response occurred, and the duration at which the first of three successive correct responses occurred. On the occasions when matched words were presented, the experimenter also recorded the occurrence and nature of any overt intrusions from the rehearsed competitor. Overt intrusions were defined as recognition responses containing either of those letters in the rehearsed word that had been changed to make the matched word. When they occurred, rejection thresholds for the overt intrusions were recorded.

2.1.1 The words used.

Over the whole experiment 40 words were used. Of these, 20 were the Turkish words of seven letters used by Solomon and Postman (1952). The remaining 20 were obtained by constructing one matched word for each of the initial 20. The construction was performed by randomly selecting two of the three middle letters and replacing them by other letters chosen from the alphabet randomly, except for the restriction that the word remain pronounceable. This procedure was based on the requirement that the matched words should, at short durations, provide the same part-cues as are used in recognition of the learned words themselves. As it is a long established fact that letters at the ends of briefly displayed words are recognised better than those in the middle (Woodworth, 1938), it appears that the requirement can be met by leaving the outside letters the same and changing those in the middle. The words were typed in capitals onto cards by an IBM electric typewriter. None of the subjects had met any of the words prior to the experiment. All the words used are shown in Appendix 1.

### 2.1.2 Design

The main tasks of the design were to allow each subject to be tested under each treatment combination, and to separate the experimental effects of frequency and competition from differences due to the words themselves. Frequency and word effects were separated by a 5 x 5, subjects x frequency, latin square design. Each word therefore occurred exactly once at every frequency. This design was repeated four times to allow separation of competition and word effects. Four groups of subjects were required. Each word occurred for one group of subjects as a core word, for another as a matched word, for another as a control word, and for the last, not at all. Exactly how this was done is shown in Table 1 (Table and Figure numbers begin at 1 within each chapter).

TABLE 1 THE DISTRIBUTION OF WORD SETS ACROSS THE FOUR GROUPS OF SUBJECTS

| | GROUP | | | |
|---|---|---|---|---|
| | A | B | C | D |
| REHEARSED | 1 | 1' | 2 | 2' |
| MATCHED | 1' | 1 | 2' | 2 |
| CONTROL | 2 | 2' | 1 | 1' |

The words in each set are listed in Appendix 1.

### 2.1.3 Subjects

The design required 20 subjects. These were the first 20 undergraduates attending first year psychology lectures who volunteered to act as paid subjects. Their ages ranged from 17 to 25 years; 12 were female, eight were male. Each subject was tested individually.

### 2.1.4 Apparatus

A 3 - Channel tachistoscope supplied by Takei and Company Ltd, was used. The optical arrangement was that to be described in more detail in Section 4.1. The timer used electrically driven cams operating micro-switches. The reliability of the cam rotation gave display durations to within an error of about five milliseconds. Contact bounce on the micro-switches effectively increased this error to a value of approximately ten milliseconds.

Pre-stimulus and post-stimulus fields were of equal brightness, and slightly brighter than the stimulus field. They showed a blank white card with a lightly drawn fixation point located over the centre of the word.

## 2.2 Results

Recognition thresholds measured by the duration at which the first of three successive correct judgements occurred, differed very little from those measured by the duration at which the first correct judgement occurred. Once a correct judgement was given, the subject only rarely reverted to an incorrect judgement. It is, therefore, only necessary to consider thresholds measured at the first correct judgement. No significant differences were associated with the order in which thresholds were measured (that is, with whether the rehearsed word occurred before or after its matched word). These thresholds were therefore combined in all later analyses.

### 2.2.1 Recognition Thresholds

All the threshold measures obtained are given in Tables 1, 2, and 3 of Appendix 1. These show the thresholds for the rehearsed, matched and control words respectively. Recognition thresholds averaged over all 20 subjects, for the rehearsed, matched and control words are given in Tables 2 and 3. Thresholds for the control words are given in both tables as having a rehearsal frequency of zero. This is also how they are given in Figure 1, where the results are shown graphically.

TABLE 2 RECOGNITION THRESHOLDS FOR REHEARSED AND CONTROL WORDS RELATED TO THEIR REHEARSAL FREQUENCY

| | REHEARSAL FREQUENCY | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 5 | 10 | 25 |
| THRESHOLD IN MILLISECS. | 314 | 270 | 178 | 146 | 144 | 128 |

TABLE 3 RECOGNITION THRESHOLDS FOR UNREHEARSED WORDS AS RELATED TO THE REHEARSAL FREQUENCY OF THEIR COMPETITORS

| | REHEARSAL FREQUENCY | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 5 | 10 | 25 |
| THRESHOLD IN MILLISECS | 314 | 298 | 271 | 311 | 244 | 243 |

The effect of rehearsal frequency on thresholds for the core words is large, and closely replicates that found by Solomon and Postman (1952). As such it is simply another demonstration of the size and reliability of the phenomenon to be explained. An analysis of variance performed on the thresholds for the core words showed both the frequency and subject effects to be highly significant. The interaction term was insignificant. As a result of the latin-square design, this term includes variance due to subjects x frequency interaction, and variance due to word differences. The implication is, therefore, that both variances are small. It can be seen that the relation between thresholds and rehearsal frequency is not a logarithmic function, as is sometimes claimed, but is more sharply negatively accelerated.

The predicted increase in thresholds for the matched words, as compared with the control words, plainly did not occur. Instead, thresholds were lowered by the rehearsal of a competitor. The significance of this effect was tested by an analysis of variance comparing control word thresholds with matched word thresholds combined over all frequencies from 1 to 25. A log transformation of the threshold scores was needed to reduce heterogeneity of variance. The results of this analysis are given in Table 4.

TABLE 4: ANALYSIS OF VARIANCE OF CONTROL AND MATCHED WORD RECOGNITION THRESHOLDS

| Source of Variation | Sum of Squares | Degrees of Freedom | Mean Square | F | P |
|---|---|---|---|---|---|
| Subjects | 180,414 | 19 | 9,494 | 23.5 | $\ll .01$ |
| Competitor Rehearsal | 4,823 | 1 | 4,823 | 11.9 | $\ll .01$ |
| Subjects x Rehearsal | 16,985 | 19 | 894 | 2.2 | $< .01$ |
| Error | 145,339 | 360 | 404 | | |
| Total | 347,561 | 399 | | | |

The competitor rehearsal effect is clearly significant. The estimate of error variance, provided by this analysis, was used in t - tests comparing the control word thresholds with matched-word thresholds at each of the rehearsal frequencies separately. These tests gave values of t having the following probabilities: $< .05$ at frequencies 1 and 2, $> .3$ at frequency 5, and $< .01$ at frequencies 10 and 25. This suggests that the positive transfer from competitor rehearsal may be reduced at intermediate rehearsal frequencies. The significant interaction term suggests the possibility that thresholds for the matched words may have been raised above those of the control words by competitor rehearsal for at least some subjects.

### 2.2.2 <u>Overt Intrusions and Rejection Thresholds</u>

The number of occasions on which the whole of the rehearsed word was given as a response to its matched word, were rare. Overt intrusions were therefore taken to have occurred when the subject incorrectly named at least one of the three middle letters of the displayed word as one of the letters occurring in its rehearsed competitor and not in itself. Rejection thresholds were measured for intrusions so defined. All the rejection thresholds obtained are given in Table 4, Appendix 1. In this table a blank indicates that no overt intrusion occurred. The associated thresholds for correct recognition following rejection are also given in this table. The total numbers of intrusions summed over all subjects are given in Table 5. As there are two words at each frequency, for each of 20 subjects, the maximum number of intrusions possible is 40. Table 5 also gives the rejection thresholds on intrusion averaged over all subjects, and these results are presented graphically in Figure 2.

TABLE 5: TOTAL NUMBER OF OVERT INTRUSIONS AND MEAN REJECTION THRESHOLDS

| | REHEARSAL FREQUENCY OF INTRUDING WORD | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 5 | 10 | 25 |
| NUMBER OF OVERT INTRUSIONS (MAX = 40) | 17 | 21 | 22 | 20 | 24 |
| MEAN REJECTION THRESHOLD IN MILLISECS | 172 | 195 | 202 | 138 | 180 |

A chi-square test of the differences in the number of overt intrusions at each frequency shows that the differences do not approach significance ($\chi^2$ = 1.5, degrees of freedom = 4, P>.8). This is not the result expected on the view that an increase in rehearsal frequency leads to an increase in guessing frequency. (The overt intrusion rate was close to 50 per cent, and of these less than 20 per cent were of the whole word.)

It is difficult to test efficiently the significance of the differences in mean rejection thresholds. This is because rejection thresholds can be measured only when overt intrusions occur, and they often did not. Significance tests are not necessary, however, as the prediction that rejection thresholds increase with rehearsal frequency is clearly not supported. Any significant differences that there are will include the <u>decrease</u> in rejection thresholds with the increase in rehearsal frequency from 5 to 10. From a comparison of the results given in Tables 2 and 5 it can be seen that a rehearsed response is rejected as incorrect at durations that are just as short as those at which it is first given correctly. This would be difficult to explain if correct recognition of rehearsed words at these short durations occurred only as a guess. The difficulty is further increased by the fact that once a subject has given a correct response, he rarely reverts to an incorrect one.

### 2.2.3 The dependence of recognition on intrusion and rejection

The recognition thresholds for the matched words were divided according to whether overt intrusion occurred or not. For these two sets of thresholds means at each competitor rehearsal frequency were calculated and are given in Table 6, and shown in Figure 2.

TABLE 6: RECOGNITION THRESHOLDS, IN MILLISECONDS, OF THE MATCHED WORDS, WITH AND WITHOUT INTRUSION

| | COMPETITOR REHEARSAL FREQUENCY | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 5 | 10 | 25 |
| WITH INTRUSION | 340 | 263 | 314 | 225 | 280 |
| WITHOUT INTRUSION | 266 | 284 | 308 | 264 | 187 |

As indicated by t - tests, the differences in threshold are not significant at any frequency, nor over all frequencies combined.

The interval between rejection and recognition, averaged over all subjects and all frequencies, was 107 milliseconds, or about five presentations. There was no indication that the size of this interval varied with rehearsal frequency. This finding weakens theories of recognition in terms of competition as they imply that there should be no interval between rejection and recognition.

### 2.2.4 Summary of Results

The recognition thresholds for nonsense words were found to decrease with rehearsal in the usual manner. The recognition thresholds for unrehearsed nonsense words were affected by the rehearsal of similar words, but the thresholds were decreased, not increased. There was some evidence that this positive transfer was less with intermediate rehearsal frequencies. The probability of a rehearsed word occurring as an incorrect response to a similar word did not increase with rehearsal frequency, and neither did rejection thresholds. The occurrence of an overt intrusion did not affect the threshold of subsequent recognition. Between rejection and recognition there was a relatively large interval of about 100 milliseconds, or five presentations.

## 2.3 Discussion

This discussion is concerned with three things: the doubt these results throw on current explanations of the effect of prior experience on recognition; the failure of the experiment to decide between supplementation and input explanations in general; and the evidence, in the results, of discriminative processes.

The predictions derived from explanations of the type proposed by Solomon and Postman (1952), were not supported. These authors might argue that the first prediction (that rehearsal of a competitor raises the recognition thresholds) is intended to apply only when the displayed word has itself been rehearsed. Such a restriction could be claimed on the grounds that competition only affects supplementation, and that unrehearsed words have no supplementation to be interfered with by competition. This modified view, however, predicts that competitor rehearsal will not affect recognition thresholds for unrehearsed words. In fact, the thresholds for matched words were lowered by competitor rehearsal. Such a result cannot be accounted for by any of the currently held supplementation theories. Doubt is also thrown on these theories by the failure of overt intrusions and rejection thresholds to increase with rehearsal frequency.

Although experiment 1 shows weaknesses in current explanations, it is inconclusive. It does not differentiate between input processing and supplementation explanations in general because it is still possible to explain the results of experiment 1, while claiming that rehearsal does not alter the part-cues the subject uses. This can be done by pointing out that the middle letters may be among the part-cues extracted from the display, and not in the section the subject supplies himself. Although middle letters may not normally be amongst part-cues at short durations, they could have been in experiment 1 if subjects realized that middle letters were being changed. (One subject did indeed report such a realization.) The predictions were all tested on the basis of the assumption that the supplementary component includes the middle letters. If this assumption is false then the results do not provide a general disconfirmation of supplementation explanations. Thus the present experiment fails to solve what is commonly known as the problem of response bias, because it is based on a priori assumptions regarding which letters serve as part-cue.

Many aspects of the present results suggest the occurrence of discriminative processes. In other words, they suggest that subjects were at times processing the input in terms of the question 'Is it X?', rather than in terms of the question, 'What is it?'. Three main aspects will be mentioned. Firstly, five presentations intervened, on average, between rejection of a rehearsed competitor and correct recognition of the matched word. This indicates that the subjects were able to determine that the displayed word was not the rehearsed word far sooner than they could determine what word it was. Secondly, nearly all the overt intrusions were of one of the two changed letters only. It is probably safe to assume that in most of these cases the subject knew what the other letter of the rehearsed word was. If this is so, it is possible that he did not give it because he knew it was the wrong letter, even though he was often unable to say which was the right letter. Lastly, the thresholds for the matched words were affected by rehearsal of the competing rehearsed words, but they were independent of overt intrusions from the rehearsed words. The implication of this is that the rehearsed word may affect recognition on trials where it does not occur itself as a recognition response. This would be expected if the input were processed in such a way as to show that the displayed word was similar to, but different from, the rehearsed word.

Word discrimination, if it does occur, could explain the effect of prior experience on reaction time, reading efficiency, and on the span of apprehension, in addition to explaining the effects found in experiment 1. To offer an explanation in terms of word discrimination however, is to offer an account of how input processing may change, before it has been shown that it does change. Experimental evidence that fails to demonstrate that a change in input processing occurs, as the evidence of experiment 1 does, cannot possibly show what form the change takes. The next chapter, therefore, returns to the problem of separating the stimulus and supplementary components.

# CHAPTER 3

## SOME POINTS CONCERNING WORD RECOGNITION AND WORD RECOGNITION EXPERIMENTS

This chapter attempts to make two things more explicit: the questions being asked, and the conditions for an answer. The first requires consideration of the background notions concerning the way in which people process information in word recognition tasks, and these notions are discussed in Section 3.1. The remainder of the chapter is concerned with the methodological problems involved in answering these questions. Section 3.2 points out the inadequacy of traditional scoring procedures and the need for an explicit analysis of the word recognition situation. Section 3.3 provides some relevant terminology, and Section 3.4 offers an analysis of word identification experiments. Section 3.5 describes the technique of word discrimination and random changes, offers an analysis of word discrimination experiments, and shows how this technique provides an unbiased measure of the number of letters in the stimulus component.

In this chapter, and in the following experiments, word recognition is analysed in terms of the subject's performance on each trial, where a trial is a single presentation and the subject's report of it. There are three main reasons for this. First, such performance is most amenable to analysis. Second, such performance, being relatively simple, is a component of many other activities - including recognition threshold performance. Any findings regarding it will therefore have a more general significance than findings regarding performance that is more elaborate. Third, if the performance studied is simple there is a greater chance that the processes making it can somehow be teased apart.

### 3.1 An elementary analysis of the processes involved in word recognition

Consider the situation in which a person reproduces some aspect or aspects of a brief visual display. From our everyday knowledge of people's performance at such tasks it can be seen that the transmission of information from the display and into the report must involve the following systems:

1. Visual receptor systems.
2. Storage systems, in which the information received from the display is stored for durations longer than is possible in the receptor systems.
3. Read-out systems, which transfer information from the receptor to the storage systems.
4. Retrieval systems, whereby the stored information is used to control report.
5. Supplementation systems, through which information other than that transmitted from the display is added to the report - and which may be in part controlled by whatever information is transmitted from the display into the report.

The division of the sequence of events suggested can be more clearly seen in the block diagram of Figure 1. In this diagram arrows are used to represent those processes that are of a relatively transitory nature, and which serve predominantly to transfer information between states that are more stable. It is not proposed that any of the systems mentioned are simple or unitary; each will be a complex system in itself. It is proposed, however, that the distinctions drawn are crucial ones which cannot be ignored. It is also proposed that the basic task of research is to further analyze the component systems, and that behavioural phenomena are relevant to this analysis, but only when it can be determined in which system or group of systems they arise.

It is necessary to begin by examining more closely the nature of the systems distinguished, and the following paragraphs consider each in turn.

The visual receptor systems are defined as those whose state continually depends upon the pattern of light falling on the retinae. In other words, the information in these systems is information regarding present stimulation. Anatomically, they involve at least the retinae, the optic nerve, area 17 and probably area 18 of the striate cortex.

It is because the receptor systems are continually dependent on retinal input that storage systems must be involved in the transmission of information from presentation to reproduction in word recognition experiments. The reproduction usually occurs some seconds after the display has been removed, and it can be delayed for 30 seconds without performance loss (Sperling 1963). During this time the states of the receptor systems follow whatever new displays occur, and cannot therefore remain in the state into which they were put by the present word. The necessity of the distinction between receptor and storage systems has often been pointed out - Freud (1900), for example, presents the argument clearly. But it is interesting to note that the distinction has also frequently been denied (Gomulicki 1953). Bain, for instance, denies that, 'the impressions of sense...lie stored up in a chamber quite apart from the recipient apparatus, to be manifested again when the occasion calls.' He goes on to suggest that instead, 'The renewed feeling occupies the very same parts, and in the very same manner, as the original feeling, and no other parts, nor in any other assignable manner.' (Bain 1855, pp.355-356). The grounds on which such denials seem to be made are that the retained event has the same effects as the original event, and that retention of an event must involve repetition of that event. Neither of these arguments is very convincing. What Bain fails to notice is that if the original feeling is to be renewed it must somehow be maintained in the meantime.

The processes transfering information from reception to storage will be called 'read-out' processes in accordance with the usage of Averbach and Coriell (1961), and of Sperling (1963). This term is used because it indicates what the processes do, while carrying few confusing connotations as to how they do it. Nevertheless, the idea of 'read-out' differs little from the long established idea of 'attention'. Attention was well described, for instance, by Stewart in 1802 as a fact of common knowledge:

> For my own part, I am inclined to suppose, (though I would by no means be understood to speak with confidence) that it is essential to memory that the perception or idea that we would wish to remember, should remain in the mind for a certain space of time, and should be contemplated by it exclusively of every thing else; and that attention consists partly (perhaps entirely) in the effort of the mind to detain the idea or the perception and to exclude the other objects that solicit its notice. Notwithstanding, however, the difficulty of ascertaining in what this act of mind consists, every person must be satisfied of its reality from his own consciousness; and of its essential connexion with the power of memory. (Stewart, 1802, p.108).

In this statement Stewart even implies, as do the modern writers, that the process is sequential and cannot handle more than one 'perception' or 'idea' at a time.

Recent word has brought to light much important evidence regarding the stages of filtering, capacity limits, and principles of selection, involved in attention (Treisman 1964). From many experiments it is clear that read-out is highly selective, and is controlled by a wide variety of influences. The basic properties of read-out processes, however, are still far from clear. In this thesis, concern is limited to the read-out processes dealing with briefly presented words, and particularly with those aspects of read-out which may be modified by word familiarity.

In tachistoscopic studies of word recognition, it is generally assumed that the retrieval and use of stored information are of little or no concern. This is presumably because both the amount of material and the storage time are, typically, so small that although retrieval and use are little understood we can be reasonably sure that they are operating at near perfect efficiency. Evidence on this matter could be gained by asking for two reproductions, one some little while after the first. If no increase in accuracy occurred on the second reproduction, the assumption of near perfect retrieval on the first reproduction would be strengthened.

The supplementary systems are all those which add information to that provided by the display. Often they will serve to make up for information lost during input processing. The outline offered so far may give the impression that supplementation occurs only very late in the sequence of events. This is not intended; supplementation most probably occurs at all stages. Supplementation is not distinguished by the time at which it occurs, but by the fact that it supplies information which does not come from the stimulus. Thus in the block diagram given in Figure 1, read-out storage and retrieval, mean read-out, storage, and retrieval of information from the display.

The question with which this research is concerned can now be stated as, 'In which of the above systems does the effect of prior experience on word recognition arise?' If this question is to be answered the first step must be to separate those effects arising in the systems producing the stimulus component from those arising in the systems producing the supplementary component. The remainder of the present chapter attempts to show how this can be done.

### 3.2 Scores of word recognition

The basic data of word recognition experiments are scores relating to the degree of accuracy with which the subject reproduces the letter sequence presented to him. These are the scores which Goldiamond (1958) calls accuracy scores. But if we are studying the reception and transmission of stimulus information, these are not the scores we want. On most occasions, the accuracy of reproduction will be in part due to the reception and transmission of stimulus information, and in part due to efficient supplementation. To obtain the score that is required we must correct the accuracy score for that amount which is due to supplementation. When we are concerned with the reproduction of complex stimulus patterns, and when in addition some or all of these are familiar to the subject, it is very difficult to determine the form these corrections should take, and no adequate procedures have yet been devised.

The difficulty of devising suitable corrections is further increased by the existence of many different forms of scoring procedure, all designed according to principles that are arbitrary or unstated. Woodworth clearly recognised and described part of the problem. Discussing the method of retaining members, he said:

> It is easy to score, if we are satisfied with a simple count of the correctly reproduced items. When two O's reproduce correctly the same number of items, but one O gives the correct order and the other not, the first O clearly shows the greater memory of the presented list; but as soon as we try to devise a scoring system which shall allow partial credits, we find any system arbitrary. (Woodworth, 1938, p.8).

Scoring systems remain arbitrary, and are in addition often far from simple. The following is a typical example:

> The recall score was obtained as follows: each correct letter in the response was given one point. Letters were scored as correct if the correct letter was in the correct position. Double and triple reversals were given one point each. In addition, a single omission or intrusion was discounted from the array in marking the rest of the letters, but one point was subtracted each time this was done. A letter was considered an omission or intrusion if, after correcting for its position, the response resumed correctly for two or more consecutive letters. Thus if the stimulus was RPITCQET and the response was RPTCOETC the score was 6-1 or 5 letters. (Pylyshyn, 1965, p.284).

As long as theoretical concern is limited to a consideration of whether particular variables do or do not affect reproduction accuracy, such scoring procedures are adequate. But when an attempt is made to discover how these variables affect accuracy, the procedures are plainly inadequate, because such accuracy scores combine, in unknown proportions, the accuracy resulting from the stimulus and supplementary components. While the basic data remain so equivocal, no amount of theoretical juggling can remove the ambiguity in experimental results.

The development of adequate correction procedures is possible only if the relations between the data that we can collect and the data that we need, are analyzed explicitly and in detail. This, the remainder of the present chapter attempts to do.

## 3.3 The elements of analysis

The analysis can be made in terms of two primitive elements, from which are obtained three important, but derivative, components. The primitive elements are '<u>letters</u>' and '<u>operations</u>'; where the operations are any defined procedures for selecting and grouping letters. The derivative components are '<u>alphabets</u>', '<u>terms</u>', and '<u>dictionaries</u>'. The meanings of these words are similar to their common meanings, the main difference being that here they are more general. An '<u>alphabet</u>' for instance, is any defined set of letters, not just those sets occurring in natural languages. They could therefore contain any number of letters from zero to infinity. If these words are intended in their normal, more restricted sense, confusion will be avoided by use of phrases such as 'the English dictionary', and 'the English alphabet'.

The only property of letters required by the analysis is mutual exclusiveness. That is, if anything is a letter, then it is one particular letter and not any other. The analysis is not itself concerned with deciding letter identity. It can only be applied to situations where it has already been decided what things are letters, and what letters they are.

An alphabet is any exhaustive set of letters. It determines the number and identity of different letters available for the construction of terms, and therefore also the maximum number of different terms of any given size. A term is any selection of letters, usually, but not necessarily, in a particular order. Both ordered, and non - ordered terms may contain repetitions of letters. Finally, dictionaries are sets of terms. They are not ordered, and do not contain repetitions. (Alphabets could be called dictionaries of all possible single letter terms, but as a case of particular significance they merit their own title.)

Operations are, therefore, any defined procedures whereby alphabets, terms, or dictionaries are formed either from letters, or from other alphabets, terms, or dictionaries. The variety of different operations which are possible is unlimited. An example that shows the form such operations can take is, 'select from dictionary D any term that has no letters in common with term B.' Any defined system of letters, alphabets, terms, dictionaries, and operations is called a formative system. An infinite variety of formative systems is clearly possible, ranging from those with a single alphabet and a single operation, to those with many alphabets, terms, dictionaries, and operations. The formative system of word identification experiments is just one of these, and it is with this one that the next section is concerned.

## 3.4 An analysis of word identification experiments

### 3.4.1 The formative system

The focal point of word identification experiments is the subject's reproduction, which is a sequence of letters formed from the letters and words available to the experimenter and from the letters and words available to the subject. By describing the experimental situation as a formative system it is possible to show clearly the major steps involved in the formation of this reproduction. Once this is done the formal properties of the system can be determined. This will show whether the separation of stimulus and supplementary components is possible, and if so how it must be performed. It is essential to the purpose of the analysis that it involve no unlikely assumptions regarding word recognition and word recognition experiments. The experimental situation must therefore be analysed only into steps of whose existence and interrelation there is little doubt.

The formative system proposed is outlined in the diagram of Figure 2. For all terms, except terms Z and G, the suffix j in the symbol $K_i.j$ indicates that the symbol stands for the j th letter in the i th term K. For the terms Z and G the suffix indicates the position that the letter occupies in term R. For example, $Z_i.j$ stands for that letter in the i th term Z which when transferred to term R occupies the j th position. The reasons for describing word identification experiments as a formative system of this particular kind will first be given briefly, and then various points will be discussed in more detail.

Term X is the term which is selected from some set of terms called dictionary 1, and presented to the subject. The rules governing the selection of term X are called operation 3. Alphabet 1 is the set of letters from which dictionary 1 is formed, and the rules according to which this is done are called operation 1. Term G is the supplementary component of reproduction; it is formed by operation 5 from dictionary 2. Dictionary 2 is the whole set of terms which are available to supplement term Z. The procedures by which it is constructed are called operation 2. Finally, term R is the reproduction, which is formed by simply adding together terms Z and G. The score resulting from the experiment is always some function defined on terms X and R.

Various points require further elaboration:

1. In the formative system given here dictionaries 1 and 2 are constructed from the same alphabet. This corresponds to experiments in which experimenter and subject can be reasonably described as agreeing upon an alphabet. This will most often be the case, but it is possible to imagine situations where it is not. For many of the latter situations, however, the results derived from the present analysis will still be valid. This will be so, providing only that the subject's alphabet is a sub-set of the experimenter's alphabet.
2. The contents of the dictionaries will be most easily specified, sometimes in terms of the

operations by which they are formed, and sometimes by explicit denotation.

3. In some experiments the contents of dictionary 1 are known, but in many they are not. In experiments using English words, for instance, the set of words from which the words presented are chosen is often not definitely known, either to the experimenter or to the subject. Nevertheless, no great difficulty exists here for the experimenter is always able to choose dictionaries that he can specify whenever he needs to.

4. The case is similar with respect to dictionary 2. If the subject is instructed to use only English words, the contents of dictionary 2 cannot be exactly specified. If, on the other hand he is instructed to use a particular set of words, then there is a better chance that the contents of dictionary 2 can be specified. In cases where the subject is unable to obey the instructions an adequate description of the experimental situation might not be given by a formative system of the type proposed but by some other formative system. In many experiments this difficulty will not arise, however, as it will be a simple matter for the subject to act in the instructed fashion and produce only the terms specified as term R. In any case, most of the difficulties associated with specifying the contents of dictionary 2 can

be avoided. It will be shown in the next section that the properties with which we are most concerned can be determined without the use of any detailed assumptions regarding the contents of dictionary 2.

5. The rules governing selection of terms from dictionary 1, for presentation, are of great importance. If terms are selected in some orderly fashion, it is possible that this order could be used to select terms from dictionary 2 so that term R is always accurate but independent of term Z. It is relatively common to avoid this difficulty by randomly selecting the terms for presentation. Accordingly, only that case will be studied in which operation 3 is defined as the random selection of terms from dictionary 1. An important distinction is that between selection with replacement and selection without replacement. Random selection without replacement is by far the most common procedure, but it has the defect that it involves a continual decrease in the size of dictionary 1. This continual decrease might be used to increase the efficiency of supplementation, particularly when the number of terms in dictionary 1 is relatively small and the subject knows what terms these are. Random selection with replacement is easily achieved experimentally, greatly simplifies the analysis, and does not

require the dubious assumption that subjects are unable to use the knowledge of which words have already been presented to increase efficiency. It is therefore the procedure examined in the present chapter, and used in all later experiments.

6. Operation 4 is defined as the selection of none, some, or all of the letters of term X to form term Z. Every letter in term Z can therefore be paired with a letter in term X. Operation 4 corresponds to the sum of those events that were divided in section 3.1 into the phases of reception, read-out, storage, and use. Term Z is that group of letters, which is transmitted through all of these phases. The properties of the formative system will greatly depend on whether or not operation 4 maintains the letters of term Z in their correct position. Three different cases will be studied: ordered transfer, in which $Z_i \cdot j = X_i \cdot j$ for all j in Z; non-ordered transfer, in which the position of letters in term Z is independent of their position in term X; and mixed transfer, in which some letters are transferred as in ordered transfer, and some as in non-ordered transfer.

7. Operation 5 is defined as the selection of letters from dictionary 2 according to any rules whatsoever, providing they are independent of all letters in term X that fail to be transferred into term Z. In the diagrammatic outline, the

arrow from term Z to operation 5, indicates that the rules of operation 5 can include the use of term Z, not that they must.

8. Operation 6 is defined as the summation of terms Z and G to form term R according to the rule $Z_i.j = R_i.j$ for all j in term Z and $G_i.k = R_i.k$ for all k in term Z. It is clear from the definition of operation 6 just given that there cannot be both a letter $Z_i.j$ and a letter $G_i.j$, for if there were two different letters $R_i.j$ would result.

### 3.4.2 Definition of symbols

Let the number of:

letters in alphabet 1 = n
terms in dictionary 1 = $d_1$
terms in dictionary 2 = $d_2$
selections made by operation 3 = N
letters in term $X_i$ = $x_i$
letters in term $Z_i$ = $z_i$
letters in term $G_i$ = $g_i$
letters in term $R_i$ = $r_i$

Also let:

the permutation score = Sp and
the combination score = Sc

The permutation score, $Sp_{B,C}$, on terms B and C say, is defined as the number of letters in the two terms which are identical and in the same position. The combination score, $Sc_{B,C}$, on two terms B and C, is defined as the number of letters in term B which can be paired with a letter in term C. Letters can be paired only if they are identical, and letters in either term can be used for pairing only once. In the following the scores on the terms X and R will be written without sub-scripts, that is, simply as Sp and Sc.

In many experimental situations the values of the variables z, g, Sp, and Sc will vary from trial to trial. In these cases the values of the variables will be best described by their probability distributions and by their expected values. (The expected value of a variable, x, that takes only discrete values, is defined as $\sum_{i=0}^{\infty} f(x_i).x_i$, where $f(x_i)$ is the probability that x takes the value $x_i$.)

### 3.4.3 Some basic relations

The task of separating the stimulus and supplementary components of reproduction can now be restated. It is the task of determining the relations between E(z), E(g), and either E(Sp), or E(Sc), or both, where these four values are the expected values of z, g, Sp, and Sc respectively. Conditions must then be found under which E(z) can be calculated from only those other variables of the system whose values are known or can be determined.

To simplify the analysis only those cases will be considered where

$$x_i = x \text{ for all } i$$

$$\text{and} \quad r_i = x_i = x \text{ for all } i.$$

That is, where all terms in dictionary 1 and hence every term X are of the same size, and where the subject's reproduction is also of this size. Both of these conditions are easy to meet experimentally.

The first problem is to determine E(Sp) - i.e. the expected value of Sp.

From the definition of operation 6

$$Sp = Sp_{X,Z} + Sp_{X,G}$$

$$\therefore \quad E(Sp) = E(Sp_{X,Z}) + E(Sp_{X,G}) \qquad (1)$$

The value of $E(Sp_{X,Z})$ will depend upon the nature of the transfer. If the transfer is ordered this value will be E(z), if the transfer is non-ordered it will be a relatively simple function of E(z). [It is worth noting that if the transfer is non-ordered then $E(Sc_{X,Z}) = E(z)$.]

To determine the value of $E(Sp_{X,G})$, consider any pair of letters $G_i.j$ and $X_i.j$, when term Z is a specific term $Z_h$ and term X is a specific term $X_i$. The probability that the two letters are the same, is given by

$$\sum_{k=1}^{n} P\left[(X_i.j=k).\ (G_i.j=k)\right]$$

That is, the probability that $X_i \cdot j$ and $G_i \cdot j$ both equal some particular letter k, summed over all n different letters in the alphabet.

The probabilities may be different for different terms $Z_h$, and in actual situations they nearly always will be. The maximum number of different terms $Z_h$ possible is $2^{(x-1)}$, as each letter in term X, except for $X_i \cdot j$, may or may not be in term Z. The probability that the two letters are identical must be averaged over all these different terms Z, and must therefore be stated as

$$\sum_{h=1}^{2^{x-1}} \sum_{k=1}^{n} P[Z=Z_h] \cdot P[(X_i \cdot j=k) \cdot (G_i \cdot j=k) \quad Z_h]$$

Now the average value of $Sp_{X,G}$ when term X equals $X_i$, will be this value summed over all g letters in term G, that is

$$Sp_{X,G} = \sum_{j=1}^{g} \sum_{h=1}^{2^{x-1}} \sum_{k=1}^{n} P[Z_i=Z_h] P[(X_i \cdot j=k) \cdot (G_i \cdot j=k)[Z_h]$$

Finally, this value may very well differ from one term in dictionary 1 to another, so that $E(Sp_{X,G})$ must be expressed as the average value of this expression over all $d_1$ terms.

$$E(Sp_{X,G}) = \frac{1}{d_1} \sum_{i=1}^{d_1} \sum_{j=1}^{g} \sum_{h=1}^{2^{x-1}} \sum_{k=1}^{n} P[Z_i=Z_h] P[(X_i \cdot j=k) \cdot (G_i \cdot j=k)[Z_h] \quad (2)$$

A similar expression can be derived for the value of $E(Sc_{X,G})$.

Equations 1 and 2 are quite general, and state the basic relations in the relatively simple type of word recognition experiment we are here considering. They state explicitly the problems that must be solved by <u>any</u> experiment endeavouring to separate the stimulus and supplementary components of word recognition performance. To achieve this separation the value of $E(Sp_{X,G})$ must be determined, and equation 2 shows that this is impossible if the distributions of the $Z_h$, $X_i.j$, and $G_i.j$ are unknown. In nearly all traditional experiments on word recognition (and in all that use words chosen from an existing language) all three distributions are unknown, and so division of the accuracy scores obtained in these experiments into stimulus and supplementary components is impossible. Thus the above considerations provide a general proof of the conclusion arrived at in Section 1.3, where particular experimental designs were examined in detail.

The most difficult problem, as can be seen from equation 2, is that the value of $Sp_{X,G}$ depends on the exact contents of term Z. In other words, the amount of accuracy due to guessing usually depends on exactly what information from the stimulus is used. In most actual situations this would indeed be the case. Therefore a correction for guessing is only possible if we already know what information from the stimulus is used. But it is because we do not know this that we need the correction.

Fortunately, there are some specific situations in which it is possible to determine the value of E(z) without prior knowledge of exactly how the $Z_h$ are distributed. One is where the value of $E(Sp_{X,G})$ is the same for all $Z_h$ of any given size. This situation is analyzed in detail in Section 3.4.4. Another, is where, for all $Z_h$ of any given size, the value of $E(Sp_{X,G})$ is the same within each of a number of classes of $Z_h$, and where it is known with what probability a $Z_h$ is in each of these classes. This is the situation made use of by the method of random changes, and is analyzed in detail in Section 3.5.

### 3.4.4 Dictionary 1 complete

Let $x_a$, $x_b$, $x_c$.... $x_n$ be the different sizes of terms in a dictionary. The dictionary is called complete if it contains all the terms of size $x_a$, $x_b$, $x_c$, .... $x_n$ that it is possible to construct from its associated alphabet. The case considered first is that in which dictionary 1 is complete.

#### 3.4.4.1 Ordered transfer

Ordered transfer is that in which $Z_i.j = X_i.j$ for all i and all j. This corresponds to the case in which all letters transferred from the display to the reproduction maintain their correct position. First consider the case where z is constant over all N repetitions of operation 3.

We begin with equation 1

$$E(Sp) = E(Sp_{X,Z}) + E(Sp_{X,G})$$

From the definition of operation 3 for ordered transfer

$$E(Sp_{x,z}) = z$$

To determine $E(Sp_{X,G})$ consider a single letter $X_i.j$. Because all possible terms are in dictionary 1 and selection is random, the probability that $X_i.j$ is any particular letter is $\frac{1}{n}$, for all possible terms X, and hence for all possible terms Z. Therefore

$$\sum_{h=1}^{2^{x-1}} \sum_{k=1}^{n} P[Z=Z_h] P[(X_i.j=k) \ (G_i.j=X \ k) | Z_h]$$

$$= \sum_{h=1}^{2^{x-1}} \sum_{k=1}^{n} P[Z=Z_h] \frac{1}{n} P \ [(G_i.j=k) | Z_h]$$

$$= \frac{1}{n}$$

This is so, no matter how the $G_i.j$ and $Z_h$ are distributed, because the summations over both h and k are exhaustive. But this is true for all g letters in term G, and for all terms in dictionary 1, therefore from equation 2

$$E(Sp_{X,G}) = \frac{1}{d_1} \cdot d_1 \cdot \frac{g}{n}$$

$$\therefore \quad E(Sp_{X,G}) = \frac{g}{n} \qquad (3)$$

As $r = g + z$ and $x = r$

$$g = x - z$$

$$\therefore E(Sp_{X,G}) = \frac{x - z}{n}$$

Substituting in equation 1

$$E(Sp) = z + \frac{x - z}{n}$$

and thus $z = \dfrac{n\ E(Sp) - x}{n - 1}$ (4)

All values on the R.H.S. of this expression are values that are known or can be determined.

Now consider the case where z is not constant over the N repetitions of operation 3. Let the probability that term Z has $z_i$ letters be given the value of $f(z_i)$. Then, as before,

$$E(Sp) = E(Sp_{X,Z}) + E(Sp_{X,G})$$

But now $E(Sp_{X,Z}) = \sum_{i=0}^{x} f(z_i)\ z_i = E(z)$

and, from 3, $E(Sp_{X,G}) = \sum_{i=0}^{x} f(z_i)\ \dfrac{g_i}{n} = \sum_{i=0}^{x} f(z_i)\ \dfrac{(x - z_i)}{n}$

$$= \frac{x}{n} \sum_{i=0}^{x} f(z_i) - \frac{1}{n} \sum_{i=0}^{x} f(z_i)\ z_i$$

$$= \frac{x}{n} - \frac{E(z)}{n}$$

$$\therefore E(Sp) = E(z) + \frac{x - E(z)}{n}$$

and $E(z) = \dfrac{n\ E(Sp) - x}{n - 1}$ (5)

$E(z)$ can thus be determined independently of whether or not $z$ varies from trial to trial.

This derivation carries a most important implication. In the preceding analysis it has been assumed that the transfer of letters is an all-or-none affair. Empirically this may not always be the case; but even if transfer is not all-or-none equation 5 remains appropriate. Any transfer from term X to term Z, for instance, that involved parts of letters rather than whole letters, would be equivalent to some probability function $f(z)$, and equation 5 was derived for all $f(z)$. It seems reasonable, therefore, to view $E(z)$ as giving the average number of letters transferred from term X to term Z independently of whether or not the transfer is all-or-none.

### 3.4.4.2 Non-ordered transfer

In this case z letters are taken from term X to form term Z but their position in term Z is independent of their position in term X. The problem is to determine the relation between E(Sc) and E(z).

First, consider the case where z is constant. From the definition of operation 6 and Sc

$$Sc = Sc_{X,Z} + Sc_{(X-Z),G}$$

and $\therefore \quad E(Sc) = E(Sc_{X,Z}) + E(Sc_{(X-Z),G})$

The last term is $Sc_{(X-Z),G}$ and not $Sc_{X,G}$ because, by the definition of Sc, letters are only available for pairing once. Each letter from term Z will pair with one letter in term X leaving only the remainder of term X for pairing with term G. From the definition of operation 3

$$E(Sc_{X,Z}) = z$$

The problem is to determine the value of $E(Sc_{(X-Z),G})$. That is, to determine the average number of letter pairings that can be made, regardless of position, between two independently selected terms of g letters. As in the case of ordered transfer, the terms can be assumed to be independent because operation 3 is random selection from a complete dictionary. It might be expected that $E(Sc_{(X-Z),G})$ would be as easy to determine as $E(Sp_{X,G'})$ but it appears to be extremely difficult. The following derivation is the most simple it has been possible to find.

Let $L_{a,j}$ be the number of times that the j th letter of alphabet 1 occurs in term (X-Z). Let $L_{b,j}$ be the number of times the j th letter of alphabet 1 occurs in term G. The number of pairings involving j th letter of alphabet 1 will be whichever of $L_{a,j}$ and $L_{b,j}$ is the smaller. Call this value $L_j$.

$$Sc_{(X-Z),G} = \sum_{j=1}^{n} L_j$$

and
$$E(Sc_{(X-Z),G}) = \sum_{j=1}^{n} E(L_j)$$

The distribution of the $L_{a,j}$ and $L_{b,j}$ is given by:

$$P[L_{a,j} = w] = P[L_{b,j} = w] = \binom{g}{w}\left(\frac{1}{n}\right)^{w}\left(\frac{n-1}{n}\right)^{g-w}$$

As the terms (X-Z) and G are independent, the $L_{a,j}$ and $L_{b,j}$ are independent, and their joint distribution is given by

$$P[L_{a,j}=w; \text{ and } L_{b,j}=v] = \binom{g}{w}\left(\frac{1}{n}\right)^{w}\left(\frac{n-1}{n}\right)^{g-w} \binom{g}{v}\left(\frac{1}{n}\right)^{v}\left(\frac{n-1}{n}\right)^{g-v}$$

$$= \binom{g}{w}\binom{g}{v}\left(\frac{1}{n}\right)^{w+v}\left(\frac{n-1}{n}\right)^{2g-w-v}$$

Call the R.H.S. of this equation $f(w,v,g,n)$

$$\therefore \quad E(L_j) = \sum_{w=0}^{g}\sum_{v=0}^{g} L_j\, f(w,v,g,n)$$

By summing separately the cases in which $w>v$, $w=v$, and $w<v$ this expression may be rewritten as

$$E(L_j) = \sum_{w=1}^{g}\sum_{v=0}^{w-1} + \sum_{w=0}^{g}\sum_{v=w} + \sum_{w=0}^{g-1}\sum_{v=w+1}^{g} L_j f(w,v,g,n) \qquad (6)$$

But $$\sum_{w=1}^{g}\sum_{v=0}^{w-1} L_j f(w,v,g,n) = \sum_{w=1}^{g}\sum_{v=0}^{w-1} v f(w,v,g,n) \qquad (7)$$

as in every term $v<w$, and $L_j$ = whichever is the smaller of v and w. The third term in the expression on the R.H.S. of equation 6 is also equal to the R.H.S. of 7, since

$$\sum_{w=0}^{g-1}\sum_{v=w+1}^{g} L_j f(w,v,g,n) = \sum_{w=0}^{g-1}\sum_{v=w+1}^{g} w f(w,v,g,n)$$

$$= \sum_{v=0}^{g-1}\sum_{w=v+1}^{g} v f(w,v,g,n)$$

by simply interchanging v and w, which are only variables of summation.

$$= \sum_{v=0}^{g-1}\sum_{w=v+1}^{g} v \binom{g}{w}\binom{g}{v}\left(\frac{1}{n}\right)^{w+v}\left(\frac{n-1}{n}\right)^{2g-w-v}$$

Which is most easily evaluated when written as

$$\sum_{w=0}^{g-1}\sum_{v=w+1}^{g} L_j f(w,v,g,n) = \sum_{v=0}^{g-1} v.b(v;g,\tfrac{1}{n})k(v;g,\tfrac{1}{n})$$

Where: $b(v;g,\frac{1}{n})$ is the probability that the binomial variable takes the value v in g trials when the probability of success is $\frac{1}{n}$, and $k(v;g,\frac{1}{n})$ is the probability that the binomial variable takes a value greater than r in g trials when the probability of success is $\frac{1}{n}$. The values of these functions for different values of v, g, and $\frac{1}{n}$ are widely tabulated. The second term in the expression in the R.H.S. of equation 6, can also be expressed in terms of the binomial function.

$$\sum_{w=0}^{g}\sum_{v=w} L_j f(w,v,g,n) = \sum_{v=0}^{g} v[b(v;g,\tfrac{1}{n})]^2$$

Substituting these values in equation 6

$$E(L_j) = 2\sum_{v=0}^{g-1} v.\ b(v;g,\tfrac{1}{n})k(v;g,\tfrac{1}{n}) + \sum_{v=0}^{g} v[b(v;g,\tfrac{1}{n})]^2$$

As $$E(Sc_{(X-Z),G}) = \sum_{j=1}^{n} E(L_j)$$

$$E(Sc_{(X-Z),G}) = n\ E(L_j)$$

because the value of $L_j$ is identical for all the n letters.

$$\therefore E(Sc_{(X-Z),G}) = 2n \sum_{v=0}^{g-1} v.\ b(v;g,\tfrac{1}{n})k(v;g,\tfrac{1}{n}) + n\sum_{v=0}^{g} v\ b(v;g\tfrac{1}{n})^2$$

$\therefore$ As $E(Sc) = E(Sc_{X,Z}) + E(Sc_{(X-Z),G})$

and $g = x - z$

$$E(Sc) = z + 2n\sum_{v=0}^{x-z-1} v.\ b\ (v;x-z,\tfrac{1}{n})k(v;x-z,\tfrac{1}{n})$$

$$+ \sum_{v=0}^{x-z} v[b(v;x-z,\tfrac{1}{n})]^2 \qquad (8)$$

To check the validity of this result all possible outcomes in some simple cases, where x and n are small, were enumerated. The values of E(Sc) determined from these enumerations were found to be the same as those given by equation 8 for the same values of x and n.

In experiments all values of the variables in equation 8 will be known except for z. Because of its complexity the only way to solve equation 8 for z is to tabulate the values of E(Sc) resulting from each integral value of z. With words of normal length this is an easy task.

The case where z is not constant is even more complicated. However, providing the variance of z is not larger than one or two letters, the value of E(z) corresponding to any given value of E(Sc) can be estimated by graphical interpolation. For this interpolation the tables of corresponding values of z and E(Sc) calculated from equation 8 can be used.

It is possible to make an exact determination of the value of E(z) for the case in which z varies, but it involves a more detailed analysis of the experimental results. It requires the determination not of E(Sc) but of $f$(Sc), where $f$(Sc) gives the probability that Sc takes each possible value from zero to x. The increase in accuracy gained by the exact solution does not seem large enough to warrant the large amount of extra work entailed. Therefore the approximate method is used in all experiments reported below.

### 3.4.4.3 Mixed transfer

It is important to consider the case of mixed transfer as it is probably one that often occurs empirically. In mixed transfer operation 3 is such that the position of letters in term Z is, for some letters, the same as their position in term X, and for other letters, independent of their position in term X. The proportions of the two kinds of transfer can always be calculated, where necessary, because these proportions determine a particular pair of values for the two scores E(Sp) and E(Sc). The value of E(z) calculated from E(Sc) gives the average number of letters in term z irrespective of the correctness of their position. The value of E(z) calculated from E(Sp) gives the average number of letters correct with respect to both identity and position. The average number of letters in term Z whose transfer is independent of position is therefore related to the difference between the two values of E(z) calculated from E(Sc) and E(Sp). Determination of the exact nature of this relationship is not necessary for our present purposes.

#### 3.4.4.4 Complete dictionaries and the separation of stimulus and supplementary components

The corrections of the accuracy scores given by equations 5 and 8, provide estimates of the number of letters received from the stimulus and transmitted into the reproduction, which are unbiased by any form of supplementation. In addition they provide a means for differentiating between the transfer of information regarding letter identity and that regarding letter position.

Applied to the problem of determining whether prior experience affects the stimulus component, a possible solution is seen in the case with which the accuracy scores can be corrected for guessing when dictionary 1 is complete. These corrections are valid no matter whether the subject has had prior experience of the words in dictionary 1 or not. It would therefore be possible to investigate the effect of prior experience on the stimulus component by using complete dictionaries and varying the subjects experience with them. No such investigation has yet been made. An immediately apparent difficulty is that complete dictionaries will usually be very large. For instance, in a complete dictionary of three letter terms made from the English alphabet, there are $26^3$ different terms. Adequate rehearsal of the whole dictionary, or even a significant portion of it, would clearly be very difficult to achieve. This difficulty could be overcome, however, by the use of smaller alphabets.

### 3.4.4.5 Optimum readiness

It is reasonable to assume that the subject is in a state of optimum readiness when he is ready for just one particular, highly overlearned, word. The separation of stimulus and supplementary components by use of a complete dictionary as just suggested has the great weakness that it is not applicable to such conditions of optimum readiness. A study of performance under these conditions is essential, because, if prior experience does affect the stimulus component, then it is under conditions of optimum readiness that it is most likely to do so. If, on the other hand, there is no effect of prior experience on the stimulus component, then it is under conditions of optimum readiness that this must be demonstrated. For to demonstrate the absence of the effect under less optimum conditions, is not to exclude its possibility under more optimum conditions. The basic theoretical issue is therefore most likely to be settled by the use of techniques able to measure the degree of stimulus control of word recognition under conditions of optimum readiness. Techniques that meet this need are developed in the next section.

## 3.5 Word discrimination and random changes

### 3.5.1 The method of word discrimination

Word discrimination as a method is simply a matter of asking the subject the question 'Was this word displayed?', rather than, as in word identification, 'What word was displayed?'. Postman (1963) notes that the crucial difference between psycho-physical and word recognition procedures is that the former use a very restricted range of responses (e.g. yes or no), whereas the latter use a very wide range of responses. It is now generally agreed that the use of a wide range of responses raises very great difficulties of interpretation (see, for example, Hake and Rowan, 1966). It is a most important feature of the word discrimination method that it removes this difference between psycho-physical and word recognition procedures, and thereby all of the problems associated with the use of a wide range of responses. In spite of this virtue practically no use has been made of the method to study word recognition. The most probable reason for this is that word discrimination seems to require so little stimulus information that it can provide no detailed evidence regarding the perception of complex stimulus patterns. In addition, the method of word discrimination seems to necessitate preparing the subject for one particular word. It will be shown, however, that both of these deficiencies can be remedied; the first by the method of random changes described in the next section, and the second by procedures described in Chapter 4.

### 3.5.2 The method of random changes

In the method of random changes the subject must discriminate a briefly displayed word from a specified word. On trials selected at random, the briefly displayed word is the same as the specified word, and on the other trials it is different. When it is different only one letter is changed, and this letter is selected at random and changed to another letter selected at random.

To understand the method of random changes consider the situation in which a subject is briefly shown a familiar word, say TABLE, and he correctly says what it is. The experimenter's problem is to discover how much of the stimulus the subject actually determined to have the stated identity; that is, he must discover whether the subject actually determined that the first letter was T and not some other letter, that the second was an A and not some other letter, and so on. The most simple - and perhaps the only possible - way to find this out is to change parts of the stimulus and see whether the change is detected. To estimate detection rates accurately, however, change and no-change trials must occur at random. It is only under these conditions that the subject must detect the change in order to respond differentially to change and no-change trials. The way in which the stimulus is changed, on change trials, is also crucial. If the letters changed are selected in a biased or orderly manner, then performance will depend, not upon the number of letters the subject discriminates, but upon which he discriminates. For this reason it is necessary that the letters changed be selected at random. Only then is it impossible for the subject to bias discrimination in favour of letters that are more likely to be changed.

The most important feature of the method of random changes is that it enables the experimenter to calculate the number of letters discriminated. The subject's ability to detect the change will depend on two things: the number of letters changed, and the number of letters discriminated. The experimenter knows the first, and therefore in the right conditions can calculate the second. Exactly how this is done is shown in the next section.

### 3.5.3 Calculation of the number of letters discriminated

The formative system which can be used to analyse word discrimination experiments is very similar to that used for word identification experiments. The main difference is in the nature of term R and operation 6. Term R will have only two states: one corresponding to the response indicating identity, and the other to the response indicating difference. Operation 6 will form term R by comparing terms Z and G with some other term. This other term will be called term C. Operation 6 is such that if the letters of terms Z and G do not match the letters of term C then term R takes the state indicating difference. The scores collected from the experiment will be some function of terms X, R, and C. Matters are greatly simplified by the fact that the only aspect of term G that is relevant to the scores is the probability that it contains a non-matching letter on occasions when term Z contains no non-matching letters.

The following analysis shows how the number of letters in term Z can be calculated from performance when the method of random changes is used.

Let the number of letters:

in the word = x
changed, when the word is different, = y
discriminated = z.

Also, let the probability that the subject:

says 'Different' when the words are different = u
says 'Same' when the words are different = s
says 'Same' when the words are the same = q

says 'Different' when no change is detected $= p$

detects the difference $= \emptyset$

The basic outcome of any experiment will be estimates of u, and q, which together describe the subject's performance. The letters discriminated are those letters of the stimulus whose identity determines response. The subject detects the difference if the letters discriminated include at least one changed letter.

To determine the relation between the number of letters discriminated and the observed scores, first consider the trials on which the word is different. The probability that the subject detects the difference is $\emptyset$. The probability that he does not detect the difference is therefore $(1-\emptyset)$. When he detects a difference he says 'Different'. When he does not he may nevertheless still say 'Different'; the probability that he does so is p. Therefore, the probability, u, that the subject says different when the word is different is given by the equation

$$u = \emptyset.1 + (1-\emptyset)\ p$$

$$\therefore \emptyset = \frac{u-p}{1-p} \qquad (9)$$

Now $\emptyset$ can also be expressed in terms of : z, the number of letters discriminated; x, the number of letters in the word; and y, the number of letters changed. $\emptyset$ is the probability that y letters, selected at random from x letters, will include at least one of z particular letters. Thus

$$\emptyset = 1 - \frac{\text{the number of ways of choosing y letters from (x-z) letters}}{\text{the number of ways of choosing y letters from x letters}}$$

$$= 1 - \frac{\binom{x-z}{y}}{\binom{x}{y}}$$

$$= 1 - \frac{(x-z)!}{(x-z-y)!\,y!} \cdot \frac{y!\,(x-y)!}{x!}$$

$$= 1 - \frac{(x-z)!\,(x-y)!}{(x-z-y)!\;x!} \qquad (10)$$

It is important to note that as the letters to be changed are selected at random this expression could be derived without any assumptions regarding which letters the subject discriminates.

The value of p may be determined by considering all the trials on which no change is detected. On some of these trials the words will in fact be the same and on others they will be different. As change occurs at random, the trials on which the words are the same will be a random selection of all trials. If, therefore, the subject says 'Different' when no difference is detected, he will be just as likely to do so when the words are the same as when they are different. Thus the probability p is also the probability that he says 'Different', when the words are the same. This probability is (1-q), and therefore

$$p = 1-q \qquad (11)$$

Substituting in equation 9 the values given by equations 10 and 11, we get

$$1 - \frac{(x-z)!(x-y)!}{(x-z-y)!\ x!} = \frac{u-1+q}{q}$$

$$\therefore \frac{(x-z)!(x-y)!}{(x-z-y)!\ x!} = \frac{1-u}{q}$$

But $\quad 1-u = s$

$$\therefore \frac{(x-z)!(x-y)!}{(x-z-y)!\ x!} = \frac{s}{q} \qquad (12)$$

In experiments the values of all the variables in this equation, except for z, are known or can be estimated, and z can thus be calculated.

In the particular case where y-1 equation 12 simplifies and is easily solved for z.

When y=1

$$\frac{(x-z)!(x-y)!}{(x-z-y)!\ x!} = \frac{(x-z)!(x-1)!}{(x-z-1)!\ x!}$$

$$= \frac{(x-z)\ (x-z-1)!(x-1)!}{(x-z-1)!\ x\ \ (x-1)!}$$

$$= \frac{x-z}{x}$$

$\therefore$ From equation 12

$$\frac{x-z}{x} = \frac{s}{q}$$

$$\therefore \quad z = x(1-\frac{s}{q}) \qquad (13)$$

This equation also holds if z is not constant, but varies from trial to trial.

For then from 12 $\quad \frac{s}{q} = \sum_{i=0}^{x-y} \frac{(x-z_i)!(x-y)!}{(x-z_i-y)!\ x!} \cdot f(z_i)$

Where $f(z)$ is the probability function of z.

When y=1 this simplifies to

$$\frac{s}{q} = \sum_{i=0}^{x-1} \frac{x-z_i}{x} \cdot f(z_i)$$

$$= 1 - \frac{1}{x}\sum_{i=0}^{x} z_i f(z_i)$$

$$= 1 - \frac{E(z)}{x}$$

$$\therefore E(z) = x(1-\frac{s}{q}) \qquad (14)$$

The method of random changes and equation 14 provide a measure which has long been needed. They allow an estimate of the number of letters of a presented word which are used to determine word recognition, that is, the number of letters in the stimulus component. Most importantly, this estimate cannot be biased by any form of supplementation, and can be used to assess the effect of any kind of prior experience, including optimum readiness.

### 3.5.4 The relation of letter discrimination and identification scores

The values calculated from identification experiments by the equations developed in Section 3.4, and those calculated from discrimination experiments by equation 14, are estimates of the same thing. Both are estimates of the number of letters in the stimulus whose identity is used to determine response. Perhaps one of the most useful functions of the corrections developed in the above sections is that they make possible the comparison of performance across experiments with different tasks and scoring procedures. Without these corrections no comparison would be possible, for the raw scores from the two kinds of experiments are in no way comparable.

Although the two kinds of experiments both allow calculation of the number of letters in stimulus component, there are no *a priori* grounds for assuming that the type of task has no effect on the stimulus component. Whether it does or not is purely an empirical matter. The important point is that investigation of the matter is made possible by our ability to calculate E(z) from the raw scores. Before comparisons between values of E(z) calculated in the two different ways can be made, it is first necessary to determine how the values calculated from discrimination scores depend on position information. Does correct discrimination depend on the identity and position of letters, or on letter identity alone? In most cases this question is easily answered. When the changed letter is changed to a letter that exists nowhere else in the word, then only the identity of the letter is relevant to difference detection. The value of E(z) calculated from these trials is therefore the number of letters displayed whose identity determines recognition. However, when the changed letter is changed to a letter that already exists somewhere else in the word the question cannot so easily be answered. In these cases difference detection may involve either the identity and position of the changed letter, or only its identity, but together with the identity of the already existing letter. Because of this the meaning of E(z) calculated from such cases is difficult to determine. All values of E(z) calculated from discrimination experiments are therefore based only on cases where the change is to letters not already in the word. This value is then comparable with the value of E(z) calculated from E(Sc) in identification experiments.

It is worth noting the basic property which makes separation of the stimulus and supplementary components possible if a complete dictionary or the method of random changes is used. This property is in both cases the absence of stimulus bias. That is, in both cases the aspects of the stimulus on which performance depends (letter identity in one case, and letter change in the other) vary randomly. It is not through the control of response bias that the problem is to be solved, but through the removal of stimulus bias.

## 3.6 Summary

The first section of this chapter attempted to make clear what questions were being asked regarding the processing of information in word recognition. An elementary analysis of the processes involved claimed to show a number of distinct systems, and the problem was stated to be that of finding out through which of these systems prior experience modifies word recognition performance.

As a first step towards solving this problem, the remaining sections developed procedures for calculating the number of letters in the stimulus component. These calculations were developed for word identification performance when a complete dictionary is used, and for word discrimination performance when the method of random changes is used. The method of random changes was described as one in which, on randomly selected trials, randomly selected parts of the word are changed. The subjects' ability to differentiate between change and no-change trials was shown to depend on the amount of the stimulus discriminated, and to allow that amount to be calculated.

# CHAPTER 4

## GENERAL METHODS

In the following experiments the degree of stimulus control over word identification and word discrimination was studied and compared. For word identification a complete dictionary 1 was used, and no variations in prior experience were induced, the subject being given no experience of the word prior to its brief display. For word discrimination the method of random changes was employed, and a variety of prior experiences were induced. This chapter describes the methods and procedures that were common to these experiments.

### 4.1 Apparatus

The optical system from a Takei 3 - channel tachistoscope, Model 202,[1] was used, with the mechanical timer replaced by a more accurate and flexible electronic timer. The whole apparatus is shown in Figures 1 and 2. In two channels material was seen in normal orientation, and in the third - the background field - in mirror reversal. Viewing was binocular, and through partially silvered glass. The stimulus material in each of the three channels was at the centre of an illuminated white screen (8" x 8"), and at a distance of 31.5 inches, from the viewing aperture. The stimulus words were fed into the

[1] Takei and Company Limited, Tokyo, Japan.

tachistoscope on rolls of photographic paper, and passed close behind a narrow window cut in the screen. An alignment indicator allowed rapid and exact positioning of the word in the centre of the window.

Each channel was lit by two five watt fluorescent tubes. It was found that the rise and decay characteristics of light output varies widely across individual fluorescent tubes. Those used had rise and decay times of about two or three milliseconds. An oscilloscope, linked to phototubes, enabled the duration and intensity of background and stimulus field illumination to be monitered during experiments. Fields could be monitered separately or concurrently. Typical traces for a 100 millisecond display are shown in Figure 3. Monitering led to the detection and correction of a number of gross accidental changes in display characteristics. For the background field and stimulus field 2, illumination, as measured by a Weston Photometer, Model 585, was 44 lumens/sq.ft. For stimulus field 1, in which the target word was shown, it was 22 lumens/sq.ft. The degree of dark adaptation was kept approximately constant by maintaining the room and stimulus field illumination at about the same level. To produce the required display sequences, current to the fluorescent tubes was switched on and off by impulses from an Iconix Waveform Generator, Model 5656.[1] This was achieved by coupling the Waveform Generator to the Takei tachistoscope through a switching

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[1] Iconix, 945 Industrial Avenue, Palo Alto, California, U.S.A.

unit designed by Dr J.R. Trotter of the Phychology Department, at the Australian National University. The resulting arrangement allowed great accuracy and flexibility in the setting of display sequences.

4.2 Display sequences

In order to study the rate at which word displays of normal intensity, contrast, and size are processed, it is essential to have control over the duration for which the visual display is effectively available. Because of the persistance of vision little control is obtainable when the normal blank pre-stimulus and post-stimulus fields are used. Far greater control is achieved by the use of visual noise fields. A visual noise field is one which makes illegible either a visual display or a persisting image. One form of noise field is a very bright flash which follows the stimulus display after a short interval (Lindsley and Emmons, 1958), but Sperling (1963) notes that this noise field may fail in its task by evoking negative after-images of the stimulus field. He used, instead, haphazardly patterned noise fields designed to make any persisting image illegible. Patterned noise fields of this kind were used throughout the experiments to be reported. The two noise fields used are shown in Figure 4. A small red dot in the centre of each field served as the fixation point. Noise field one was used in experiment 2, and the other in all remaining experiments. The change was made only in an attempt to increase the 'noisiness' of the field. The importance of using noise fields will be further discussed in the next chapter.

For convenience the briefly displayed word will be called the target word, and that with which it was compared on discrimination trials will be called the comparator word. Trials on which the target and comparator words were the same will be called 'same' trials, and those on which they were different will be called 'different' trials.

In word identification trials the display sequence was a brief display of the target word preceeded and followed by the noise field. In word discrimination trials the brief display of the target word was followed by a display of the comparator word. This procedure has two advantages: first, the subject can be told the comparator word prior to the brief display, but he need not be; and second, the subject can make his judgement while looking at the comparator word, thereby avoiding the errors that could be caused by a faulty memory of it. The comparator word was displayed for four seconds, this value being chosen on the basis of preliminary experiments which showed that most judgements were made within this time. The noise field was shown during the interval between target and comparator word displays. Preliminary experiments indicated that variations in this inter-stimulus interval had surprisingly little effect on performance, at least within the range from 0.1 to 3.0 seconds. The inter-stimulus interval used for all later experiments was 400 milliseconds. This probably allows the intervening noise field to achieve maximum erasure, but also keeps the interval relatively short. The display sequence in word discrimination trials was therefore as shown in Figure 5.

In all experiments the subject initiated the onset of the brief display by pressing a button on the response box. The rest of the presentation sequence then proceeded automatically. At the beginning of experiments, subjects were given practice in the co-ordination of fixation and triggering.

## 4.3 The stimulus words

The effect of word familiarity on recognition thresholds is known to increase with word length (McGinnies, Comer, and Lacey, 1952); the effect is therefore most easily studied by using relatively long words. For this reason only words containing seven letters were used. It is also the case that nearly all investigations of the familiarity effects have used pronounceable words. Apart from the findings of Beuchet (reported by Wohlwill (1966) and judged by him to be equivocal), familiarity effects with unpronounceable words have not yet been clearly shown. For this reason it was thought best to use pronounceable words. It was also necessary, however, to use words that allowed accurate corrections for guessing. If the words were randomly selected from all possible sequences of seven letters few would be pronounceable. To satisfy both requirements, the words used were constructed so that the letters 1, 3, 5 and 7 were always consonants, and so that the letters 2, 4 and 6 were always vowels; that is, all words had the form CVCVCVC. As the consonants and vowels were selected randomly and independently, the corrections derived in Chapter 3 could be used but they had to be applied to the consonants and vowels separately. Use of this standard word structure has the added advantage of reducing any variability in performance that may arise from differences in word structure. To further increase standardization of structure, and to ease calculations, the letter y was omitted from the alphabets used. The total number of words available was thus $20^4 \times 5^3$ ( $= 2 \times 10^7$). Of these, more than 1,000 were used. Random number tables were employed to construct all words.

The words - all in capitals - were photographed directly onto the rolls of photographic paper, by a Varityper Headliner, Model 840.[1] A typemaster ML - V1250 was used, which gives 12-point print. Letters so produced are about 1/8" high. The resulting stimulus materials are shown in Figure 6, which gives an example of the two strips of words required for word discrimination.

## 4.4 Response and scoring procedures

In word discrimination trials, the subject was required to say either 'Same' or 'Different', on every trial. He could do so whenever he wished after the onset of the comparator word. The experimenter recorded

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[1] Varityper Corporation, 720 Frelighuysen Avenue, Newark 14, New Jersey, U.S.A.

the subject's response on a score sheet, which also showed whether the words were in fact the same or different, and if different, which letter had been changed. From these records the average number of letters discriminated was calculated by Equation 14 of Chapter 3.

In word identification trials the subject wrote the letters on a roll of paper marked with a matrix seven cells wide. After each trial, the subject wound the paper on, making another blank grid available, and removing the last from view. Subjects were required to place a letter in each of the seven cells on every trial. They were required to place only consonants in cells 1, 3, 5, and 7, and only vowels in cells 2, 4, and 6. To remind them of this the letters CVCVCVC were placed in permanent view at the head of the relevant columns.

To score these reproductions the average values of Sp and Sc were determined, and corrected for guessing by Equations 5 and 8 respectively. It will be remembered that the value of z calculated from Sp is the number of letters identified where position is taken into account, and that calculated from Sc is the number of letters identified where position is not taken into account. As already mentioned, these corrections were performed on the consonants and vowels separately. The correction of Sp for consonants is given by the equation

$$E(z)_C = \frac{20\ E(Sp) - 4}{19}$$

where E(Sp) is estimated by the average value of Sp for consonants. Similarly, E(z) for vowels is calculated by

$$E(z)_v = \frac{5\ E(Sp) - 3}{4}$$

The estimated value of E(z) for the whole word was obtained by summing these two values. For the correction of Sc the two graphs shown in Figure 7 were drawn. Points on those graphs were plotted by determining the value of E(Sc), as given by Equation 8, for each possible integral value of E(z). The value of E(z) for each value of E(Sc) was read from these graphs. The estimated value of E(z) for the whole word was again the sum of the separate values for consonants and vowels.

## 4.5 Practice procedures and instructions

All experimental sessions were preceded by a minimum of 15 minutes practice, except when the subjects were already highly familiar with the situation. In the practice sessions the subjects were acquainted with the particular experimental conditions to be used. In experiment 2 the first session was a practice session only. Some of the subjects of experiment 2 were used again in experiment 5. In experiments 3 and 4, subjects were used for a single session only.

Verbatim instructions were not thought to be either feasable or necessary. Instead, they were given in accordance with an instruction protocol, which outlined, as clearly as possible, what the subject had to be told. Instructions were given at the start of practice and repeated whenever necessary.

## 4.6 The statistical analysis of results

Most of the effects of particular theoretical importance were large. In many cases, therefore, a relatively simple analysis of the data was sufficient. The principal means of handling the data was provided by the analysis of variance. This technique was chosen for three main reasons. (1) Subject effects are large in word recognition experiments, and therefore best removed from the error term against which treatment effects are tested. (2) Treatments were easily combined, thus permitting full factorial designs. (3) In some cases interactions between treatments were of special interest. The most suitable designs were thought to be treatment (A) x subject (S), and treatment (A) x treatment (B) x subject (S) designs. The treatments were fixed effects, and the subjects were random effects, so a mixed model was appropriate. These designs are discussed by Lindquist (1953, Chapter 6, and p.237), and by McNemar (1962, p.333). Both authors recommend them as useful and efficient designs. In these designs each subject undergoes all combinations of the experimental treatments. In the treatment (A) x treatment (B) x subject (S) design, the main effect A is tested against the A x S interaction term, and the main effect B against the B x S interaction term. The A x B interaction is tested against the three way interaction A x B x S.

Lindquist (1953, p.157) discusses the assumptions made in using the F-test with such designs. In addition to the hypothesis being tested, there are three assumptions:

1. The experimental subjects are a simple random sample from a specified population. In order to consider this assumption satisfied statistical inferences must be limited to a hypothetical population of subjects 'like those used in the experiment'. As treatment x subjects interactions are negligible in the results to be reported, this population is unlikely to be severely restricted.
2. The treatment x subjects interaction effects are normally and independently distributed in each treatment population. Lindquist (1953, p.159) states that this condition '...seems very likely to be approximately satisfied in most psychological and educational experiments.' In any case Scheffé (1959) concludes that non-normality has little effect on inferences about means.
3. The distribution of interaction effects has the same variance in each treatment population. (This assumption is equivalent to the assumption of homogeneous within-treatments variance in simple randomized designs). With regard to this assumption Scheffé (1959 p.345) says 'Inequality of variances in the cells of a layout has little effect on inferences about means if the cell numbers are equal, serious effects with unequal cell numbers.' Equal cell

numbers were used in all experiments, so tests for homogeneity of variance were unnecessary.

The way in which individual means should be compared, following an analysis of variance, is still a matter of controversy (Ryan, 1962; Wilson, 1962). The traditional procedure as given by Lindquist (1953, pp.164-166) is still widely used, and where necessary is the one adopted here.

# CHAPTER 5

# EXPERIMENT 2: THE EFFECT OF PRIOR EXPERIENCE ON THE STIMULUS COMPONENT OF WORD RECOGNITION PERFORMANCE

## 5.1 Introduction

In this experiment word discrimination was studied under two conditions of prior experience: low familiarity, and high familiarity.

1. In the low familiarity condition the subject was given no experience of the target or comparator words prior to their display for discrimination. The comparator word was randomly selected from the complete dictionary of CVCVCV's, and the target word constructed according to the method of random changes. Thus under this condition all the subject knew of the target word prior to its brief display was that it was going to be a CVCVCVC. For convenience, this condition will be referred to as low familiarity discrimination, or LFD.

2. In the high familiarity condition the subject was made well acquainted with the target and comparator words prior to their display for discrimination. Thus in this condition the subject was ready for a particular, highly overlearned,

comparator word, but did not know whether the target word would be identical to it or a random variation of it. This is the condition of optimum readiness, whose importance has already been discussed (Section 3.5). This condition will be referred to as high familiarity discrimination, or HFD.

It has already been shown how from performance under these conditions the number of letters discriminated can be calculated.

Preliminary experiments indicated large effects of prior experience on the stimulus component under these conditions. Experiment 2 was therefore designed, not only to demonstrate those effects clearly, but also to provide evidence of whereabouts in the transmission sequence they arise. The techniques developed in Chapter 3 are only capable of separating the stimulus and supplementary components. Once prior experience is shown to affect the stimulus component, it becomes necessary to develop procedures for determining whether it does so by affecting reception, read-out, storage, or use. The form such procedures may take is suggested by the following considerations.

Consider the task of reproducing a visual display that is a variant of a known display. A great reduction in informational load can be achieved if the display is recoded in terms of the known display, or, in Woodworth's terms, if it is seen as 'schema with correction'. But recoding is only useful if it occurs before the information loss, and this is only possible if a schema of the known display functions in the recoding of input prior to the loss. Thus, if we have a situation in which performance is limited by information loss occurring at known loci in the transmission sequence, we can determine whether or not recoding occurs before those loci, by showing displays which are variants of displays known to the subject.

A situation in which performance is limited by information loss occurring at known loci is provided by Sperling's method involving noise fields. When noise fields are used to erase persisting images, the duration of effective display availability is made very nearly equal to the duration of display presentation. Under such conditions the relation between performance and the duration of effective display availability can be investigated. Reporting such an investigation, Sperling says:

> The point of all these experiments is that, under a variety of conditions, random letters of good contrast are scanned at the same rate; typically, about one letter per 10 msec. However this holds true only for the first three or four letters to be scanned. Fig.5 (shown here as Figure 1) shows data obtained with the same two subjects viewing a dark pre-exposure field and a noise post-exposure field. One subject reported three, the other four letters in the first 50 msec of exposure. Additional stimulus exposure from 50 msec to 100 msec accounted for about one or two additional letters. Beyond 100 msec the rate of acquiring additional letters

> is so low as to be virtually indistinguishable from zero on this time scale. Additional data points would have shown the critical break in the curve to occur well before 100 msec.
>
> This kind of experiment perhaps more clearly than any other defines an immediate-memory span for visual materials. Letters up to the immediate-memory span can be scanned at a rate of one letter per 10 or 15 msec. This is so rapid that the rate of acquiring additional letters beyond the immediate-memory span is negligible by comparison. (Sperling, 1963, p.25-26.)

Performance at durations below the 'critical point' will be called <u>duration-sensitive performance</u>. Performance at durations above the 'critical point' will be called <u>duration-insensitive performance</u>. The critical point was at about 100 milliseconds in Sperling's experiment, but the value will vary with display conditions. Sperling takes it for granted that duration-sensitive performance shows limitations due to read-out rate, and that duration-insensitive performance shows limitations due to post read-out storage mechanisms. In this thesis much weight is placed on these claims, so an attempt is made to give them a more explicit justification.

There are three main reasons for believing duration-sensitive performance to show limitations set at read-out.

1. Duration-sensitive performance is affected by variables unlikely to have any influence after read-out. Display duration itself is the best documented example. Results to

be reported later show that this performance is sensitive to changes in display duration of as little as 5 milliseconds. Now if this performance results from limitations set after read-out, then display duration must be represented in the systems beyond read-out to within an accuracy of at least 5 milliseconds. In other words, display duration must itself be read out and transmitted into the later systems with at least this accuracy. Although possible, such an occurrence seems unlikely. (If duration-sensitive performance was shown to depend on other aspects of the display that are unlikely to be accurately read-out, such as size, shape, brightness, or contrast, this argument would be greatly strengthened.)

2. Duration-sensitive performance is highly dependent on the brightness, patterning, and contrast of both the pre-stimulus and the post-stimulus fields. For instance, unless the post-stimulus field is sufficiently 'noisy' there is no rapid decrease in performance with duration. It is unlikely that all these characteristics of the post-stimulus field are read out. If they are not, then they cannot affect information already in store. If they affect

performance, therefore, they must do so by changing the amount of information that gets into store. That is, by reducing the number of letters read out.

3. At some durations only 1 or 2 letters are reproduced. We know that the storage and retrieval mechanisms can handle more than this without loss. The implication is, therefore, that under these conditions no more than 1 or 2 letters get into storage.

The reasons for believing that duration-insensitive performance shows storage limitations are nearly as strong. There are three main reasons.

1. Such performance is little affected by specifically visual characteristics, and therefore seems to be limited by events outside the visual receptor systems.

2. Post read-out limitations can be shown to be of the right order of magnitude, for performance is very little improved when read-out is ensured by sufficiently long display durations (Baddeley, 1964).

3. The post stimulus sampling experiments of Averbach and Coriell (1961) and of Sperling (1960), show that the span of apprehension is not due to limitations in the receptor systems. In experiments of Averbach and Coriell the subject was shown an array of sixteen letters, and soon

> after the offset of the display a letter was selected at random for the subject to identify. The results show that, for a short time at least, the receptor systems make available information far in excess of the apprehension span.

If the above interpretations are correct, comparisons of the functions relating performance to duration under high familiarity and low familiarity conditions will show whether information loss is reduced by recoding in read-out, in storage, or in both.

An identification condition was also included in the present experiment. As previous studies have always related duration to performance on identification tasks, it is important to discover whether word discrimination and word identification are similarly related to duration. For this reason a word identification condition was included. Randomly selected words were briefly displayed and the subject was requested to identify each letter. As in the LFD condition the subject was given no experience of the word prior to its display. This condition is therefore called low familiarity identification, or LFI. It was expected that performance under the LFI and LFD conditions would either show that the two tasks are equivalent or that discrimination is easier. Reasons for this expectation are given in Section 5.4.4.

To summarize, experiment 2 asked four questions:

1. Does the number of letters in the stimulus component depend on prior experience?
2. Does the number of letters read out depend on prior experience?
3. Does the number of letters stored depend on prior experience?
4. Can more letters of low familiarity words be discriminated than identified?

## 5.2 Method

### 5.2.1 Outline

The experiment was required to measure and compare performance under three conditions over a selected range of display durations. The three conditions were: high familiarity discrimination (HFD), low familiarity discrimination (LFD), and low familiarity identification (LFI). The display sequences for both discrimination conditions was that shown in Figure 5 of Chapter 4. For the LFI condition it was simply the brief display of the target word preceded and followed by noise fields. Six brief durations were selected on the basis of preliminary experiments: 50,55, and 60 milliseconds were selected to show duration-sensitive performance, and 70, 90, and 200 milliseconds were selected to show duration-insensitive performance. The performance of six subjects was studied under all three conditions and at all six durations. Six experimental sessions per subject were required, each lasting about 2 hours.

5.2.2 Design

The experimental design which followed naturally from the requirements was a 3 x 6 x 6 factorial design. With such a design it is important to control serial and order effects, and in this case particularly so, because generalized practice effects are typical of tachistoscopic performance. The control of serial and order effects proceeded in three ways. First, to avoid the larger effects, as much practice as possible was given prior to the experimental conditions. Second, a counter-balanced design across subjects was used; that is, for each session all possible orders of the three conditions were used, one order per subject. Third, for each subject, conditions were given in a balanced order (ABCCBA), both within and across sessions. The full design is shown in Table 1, Appendix 2.

Complete control of serial effects would be provided by this design if serial effects were linear within sessions, or linear across sessions, or uniform across subjects. It is reasonable to assume that at least some of these conditions are well approximated. Order effects were not thought likely to influence the results. In any case, they were well controlled, as each condition followed each other condition exactly four times per subject.

### 5.2.3 Procedure and instructions

For each subject there was one practice session followed by six experimental sessions. In the practice session the subject was familiarized with the general situation and with the specific tasks to be performed. Full instructions were given in the practice session in accordance with the following protocol.

Instruction Protocol

1. Outline the purpose of the experiment in general terms as a study of how people use briefly available information. Do not allow the specific aims of the experiment to become known to the subject.

2. Seat subject comfortably and describe the required head position and fixation point. Show the subject how he is to trigger the display sequence, and request a minimum of eye movements during that sequence.

3. Describe the words to be used, their length, CVCVCVC form, and random construction. Note the omission of the letter Y. Show an example in the tachistoscope for about ten seconds.

4. Describe the discrimination task. Emphasize the randomness of identity and difference, and the random nature of the difference. Request the subject to say either 'Same'

or 'Different' on every trial, and to do so only after the onset of the comparator word. Give ten trial runs.

5. Describe the identification task. Show the seven columns in which the letters are to be written. Point out the C or V headings of the columns serving as reminders of the appropriate type of letter. Request subject to fill in all seven cells on every trial. Give five trial runs.

6. Give trial runs of 20 discriminations and 20 identifications. Tell subject how many of each were correct. Show the subject how the identifications are marked to produce the two scores Sp and Sc.

The practice session was ended by giving the subject the set of words to be used in the HFD condition of the first experimental session, with the request that he learn them. None of the words used in the practice sessions were used again.

The experimental sessions began with a five minute practice period. The experimental conditions were then given in their assigned order. A 15 minute rest was taken halfway through. The display durations within conditions were in either ascending or descending order, alternating between conditions. Under each of the HFD and LFD conditions, every subject made a total of 720 discriminations, 120 at each duration. For the LFD condition this required

720 randomly selected comparator words, because a minimum and constant state of unfamiliarity can only be maintained by presenting a word no more than once to any one subject. The same 720 words were used for all subjects. For the HFD condition repeated use of the same word is of course possible. This is fortunate, as subjects could not be expected to overlearn 720 random words. One comparator word was used per subject per session. With six subjects and six sessions, 36 randomly constructed comparator words were required. Under the LFI condition every subject made 360 identifications, 60 at each duration. For this condition 360 words were randomly constructed and each subject saw each word once.

5.2.4 <u>The random changes</u>

For the HFD and LFD conditions the target words were constructed from the comparator words according to the method of random changes. Two decisions were necessary concerning the way in which the changes were made. First, it is a consequence of random selection that changes will not occur at each letter position with exactly equal frequencies across durations and across conditions. Nevertheless, it was decided not to put a restriction on the randomness, as any such restriction might allow the subject to artificially raise performance. Second, it was necessary to decide whether changes to letters already in the comparator word should be allowed. As noted in Section 3.5.3, only changes to letters not elsewhere in the word are used for the calculation of z. This is because under such conditions the position of the letters need not be used for discrimination, and z is then strictly comparable to the value of z calculated from Sc. But it is just conceivable that if the position of the letter were never relevant, changes might occur in the way in which the subject processed the input. The compromise chosen was, therefore, to allow changes to letters elsewhere in the word, but to exclude them from the calculations.

### 5.2.5 The prior experience in the HFD condition

If the subject learned only the comparator word, then on 'different' trials, the target word would be similar to a known word but would not itself have been seen before. It is not known how the effects of learning a word transfer to similar words under these conditions, so it is preferable that the subjects learn the variant words also. To achieve this a set of variations were constructed for every comparator word used in the HFD condition. Each variant word differed from the comparator word by just one letter. One variant word was constructed for each position at which a change could occur. As the comparator word contained seven letters this required seven variant words. In this way, change could occur at random, but still produce a word known to the subject. The 36 comparator words were randomly selected, and the sets of variations on them constructed by randomly selecting a letter for each position in turn. At least one day before the experimental session the subjects were given the comparator and seven variant words to learn. They were then required to reach a learning criterion in the practice period of the experimental session. The words were presented in the tachistoscope in a set order and this series learned according to the method of anticipation.

5.2.6 Knowledge of results

Knowledge of results were given to sustain interest and motivation. At the end of each block of ten discriminations the subject was told the number correct. He was not told on which trials errors had occurred. At the start of most sessions the subject was shown the scored identifications of the previous session.

5.2.7 Subjects

The subjects were the first six psychology undergraduates who volunteered to act as paid subjects. Their ages ranged from 18 to 26 years. Two were male (R.K.M. and A.J.P.) and four were female (M.G., A.S., E.P. and T.V.). Three wore glasses (R.K.M., A.S., and T.V.).

5.3 Results

The total number of correct and incorrect responses for LFD and HFD conditions, for each subject and duration are given in Tables 2 and 3 of Appendix 2.

The percentage of correct responses averaged over subjects are given in Table 1, and shown in Figure 2.

TABLE 1 PERCENTAGE OF CORRECT RESPONSES FOR THE HFD AND LFD CONDITIONS (AVERAGED OVER SUBJECTS)

| | DURATION (MILLISECONDS) | | | | | |
|---|---|---|---|---|---|---|
| | 50 | 55 | 60 | 70 | 90 | 200 |
| L.F.D. | 58 | 64 | 66 | 62 | 71 | 81 |
| H.F.D. | 67 | 73 | 75 | 82 | 86 | 93 |

The probability of success clearly depends upon both display duration and prior experience. However, differences in the probability of success do not necessarily imply differences in the number of letters discriminated. This is because an increase in the probability of success will result from a decrease in the probability that the subject says 'Different' when no difference is detected, even if z remains unchanged. For the calculation of z the number of correct and incorrect responses for 'same' and 'different' trials separately are necessary. These numbers are also given in Tables 2 and 3 of Appendix 2.

The total number of letters reproduced correctly and in the right position under the LFI condition is given in Table 4, Appendix 2, for each subject and each duration. Table 5, Appendix 2, gives the totals when position is not taken into account. From these totals the average values of Sp and Sc for each duration were obtained, and corrected for guessing. Comparison of the two values of z so obtained for each duration shows that there is a consistent difference between them of about 0.5 or 0.6 of a letter. This means that most letters identified are also correctly located. The mean number of letters identified but incorrectly located is about half a letter.

The values of z for the LFD, HFD, and LFI conditions were obtained from the data in Tables 2, 3 and 5 of Appendix 2 respectively. These values are given in Tables 2, 3 and 4, together with the mean values over all subjects. The mean values for the three conditions are plotted in Figure 3. All the main outcomes of the experiment can be seen in this graph.

TABLE 2 THE VALUES OF z FOR THE LFD CONDITION, BY SUBJECT AND DURATION

| SUBJECT | DURATION IN MILLISECONDS | | | | | |
|---|---|---|---|---|---|---|
| | 50 | 55 | 60 | 70 | 90 | 200 |
| 1.(R.M.K.) | 2.3 | 1.7 | 3.8 | 1.8 | 3.9 | 5.1 |
| 2.(M.G.) | 3.1 | 3.1 | 3.5 | 3.0 | 4.3 | 5.8 |
| 3.(A.J.P.) | 2.4 | 2.7 | 2.6 | 1.5 | 4.2 | 5.3 |
| 4.(A.S.) | .3 | .8 | 2.0 | 1.6 | 2.3 | 4.5 |
| 5.(E.P.) | .4 | 2.8 | 1.3 | 1.7 | 3.6 | 3.8 |
| 6.(T.V.) | 1.0 | 2.7 | .1 | 1.8 | 2.1 | 4.8 |
| MEAN | 1.6 | 2.3 | 2.2 | 1.9 | 3.4 | 4.9 |

TABLE 3 THE VALUES OF z FOR THE LFI CONDITION, BY SUBJECT AND DURATION

| SUBJECT | DURATION IN MILLISECONDS | | | | | |
|---|---|---|---|---|---|---|
| | 50 | 55 | 60 | 70 | 90 | 200 |
| 1. (R.M.K.) | 2.5 | 3.6 | 3.7 | 4.8 | 5.2 | 6.1 |
| 2. (M.G.) | 3.3 | 3.9 | 3.4 | 4.2 | 4.6 | 5.6 |
| 3. (A.J.P.) | 3.7 | 4.5 | 4.8 | 4.8 | 5.4 | 6.4 |
| 4. (A.S.) | 1.4 | 2.0 | 3.0 | 3.8 | 4.4 | 5.6 |
| 5. (E.P.) | 2.4 | 2.9 | 3.4 | 3.9 | 4.7 | 5.5 |
| 6. (T.V.) | .7 | 2.0 | 3.0 | 3.5 | 4.7 | 5.8 |
| MEAN | 2.3 | 3.2 | 3.6 | 4.2 | 4.8 | 5.8 |

TABLE 4 THE VALUES OF z FOR THE HFD CONDITION, BY SUBJECT AND DURATION

| SUBJECT | DURATION IN MILLISECONDS | | | | | |
|---|---|---|---|---|---|---|
| | 50 | 55 | 60 | 70 | 90 | 200 |
| 1. (R.M.K.) | 4.0 | 4.8 | 5.5 | 6.8 | 6.4 | 6.7 |
| 2. (M.G.) | 4.3 | 5.6 | 5.8 | 6.4 | 6.3 | 6.6 |
| 3. (A.J.P.) | 5.4 | 5.5 | 5.9 | 6.4 | 6.9 | 7.0 |
| 4. (A.S.) | 2.3 | 2.2 | 5.1 | 4.9 | 5.3 | 6.9 |
| 5. (E.P.) | 2.1 | 4.1 | 3.6 | 5.1 | 5.8 | 6.2 |
| 6. (T.V.) | 3.1 | 3.7 | 4.0 | 5.7 | 4.9 | 6.5 |
| MEAN | 3.5 | 4.3 | 5.0 | 5.9 | 5.9 | 6.7 |

The relation of performance to duration was similar to that found by Sperling (see Figure 1 of this chapter). The main difference was that performance with the unfamiliar words continued to improve with increases in duration beyond 100 milliseconds, although at a markedly reduced rate. The most likely reason for this is that here the words were pronounceable whereas in Sperling's experiment they were not. As the relation of syllabic to letter coding is of interest in itself, an attempt to confirm this by a direct comparison of pronounceable and unpronounceable words would be worthwhile.

The analysis of variance performed on the z scores is summarized in Table 5.

TABLE 5 SUMMARY OF ANALYSIS OF VARIANCE OF z SCORES
(All Conditions, Subjects and Durations)

| SOURCE OF VARIATION | SUMS OF SQUARES | DEGREES OF FREEDOM | MEAN SQUARE | F | P |
|---|---|---|---|---|---|
| Condition (C) | 112.75 | 2 | 56.38 | 117 | <.001 |
| Duration (D) | 121.40 | 5 | 24.28 | 43 | <.001 |
| Subjects (S) | 41.20 | 5 | 8.24 | | |
| C X D | 10.78 | 10 | 1.07 | 4.3 | <.001 |
| S X C | 4.82 | 10 | .48 | 1.9 | NS |
| S X D | 14.29 | 25 | .57 | 2.3 | <.01 |
| S X C X D | 12.39 | 50 | .25 | | |
| TOTAL | 317.63 | 107 | | | |

Both condition and duration effects are highly significant. The critical difference for significance at the .05 level (two-tail) for individual pairs of condition means is .37. The means over all subjects and durations were for LFD 2.7 letters, for LFI 4.0 letters, and for HFD 5.2 letters. All differences are therefore significant. The significance of the C x D term means that the size of the differences due to conditions changes with duration. As the value of z under all conditions must approach seven letters as duration increases, and zero letters as duration decreases, this result is to be expected. It can be seen from the non-significance of the S X C term that the effects of the conditions did not vary across subjects.

The HFD and LFD conditions differ significantly at each of the six durations separately. This is shown by the sign test for correlated variables ($P < .02$ at each duration). The sign test also shows that the HFD and LFI conditions differ significantly at all durations except 50 milliseconds. However, an analysis of variance performed on performance under the HFD and LFI conditions at the three shortest durations, indicates that the two conditions differ at the 50 milliseconds duration also. This analysis is summarized in Table 6.

TABLE 6 SUMMARY OF ANALYSIS OF VARIANCE OF z SCORES FOR HFD AND LFI CONDITIONS AT THE DURATIONS 50, 55 AND 60 MILLISECONDS

| SOURCE OF VARIATION | SUM OF SQUARES | DEGREES OF FREEDOM | MEAN SQUARE | F | P |
|---|---|---|---|---|---|
| Condition (C) | 14.44 | 1 | 14.44 | 38 | <.01 |
| Duration (D) | 10.81 | 2 | 5.41 | 16 | <.01 |
| Subjects (S) | 27.02 | 5 | 5.40 | | |
| C X D | .13 | 2 | .07 | .3 | NS |
| S X C | 1.92 | 5 | .38 | 1.5 | NS |
| S X D | 3.28 | 10 | .33 | 1.3 | NS |
| S X C X D | 2.59 | 10 | .26 | | |
| TOTAL | 60.19 | 35 | | | |

The significance of the condition effect and the lack of a significant condition X duration interaction indicates that the conditions differ at all three durations (50, 55 and 60 milliseconds). The effect of duration is also highly significant. The critical difference for significance at the .05 level for individual pairs of means at the different durations is .52. As the means are 2.9 letters for 50 milliseconds, 3.75 letters for 55 milliseconds, and 4.3 letters for 60 milliseconds, all differences are significant. This result gives substance to the description of performance as duration-sensitive.

## 5.4 Discussion

Each of the four questions with which the experiment was concerned will be discussed in turn.

### 5.4.1 Prior experience and the stimulus component

The mean number of letters discriminated in the LFD condition over all subjects and durations was 2.7 letters, but in the HFD condition it was 5.2 letters - nearly twice as much. It has already been shown that no form of supplementation can affect these scores. The LFD and HFD conditions differed only in the subject's prior experience of the words. There can therefore be no doubt that in this experiment the number of stimulus letters controlling word recognition was greatly affected by the subjects prior experience with the presented words.

The conditions of this experiment differ in important ways from those of previous experiments in this area. Before attempting to use the present results in explanation of the commonly observed effects of prior experience, it is necessary to consider whether the phenomena observed are likely to have been affected by these differences. The three most obvious differences concern the display sequence, the type of response, and the prior experience.

1. The display sequence was different in that two displays were involved, instead of one. Preliminary experiments have shown, however,

that the second word can be omitted in the HFD condition with little effect on performance. All that is necessary is for the subject to know with which word he must compare the brief display. It is therefore unlikely that stimulus component facilitation is limited to double display situations.

2. The type of response differed in that the subject had to say 'Same' or 'Different', and was never required to say the displayed word. But as the subject knew the comparator word he could easily have been asked to name it instead of saying 'Same', and to attempt reproduction of the variant word instead of saying 'Different'. It seems unlikely that so minor a change in procedure would remove the increased degree of stimulus control over performance. This is confirmed in experiment 5 where HFD and LFI performances are compared under conditions involving identical forms of response.

3. The differences in the prior experiences seem to be the only ones likely to affect the results. Conditions of optimum readiness have not been used in most previous experiments. It is therefore important to know to what extent the results of this experiment depend upon it. This

is the problem with which the next two experiments are concerned.

In addition to the task of determining the range of conditions under which prior experience affects the stimulus component, there is the equally important task of determining the mechanism of the effect when it does occur. The only way in which the transmission sequence can be made more efficient is by the reduction of information loss, and the reduction of loss, due to word familiarity, must result from some kind of interaction between the input and a stored representation (or trace) of the familiar word. Interaction between trace and input is of course common knowledge. What these results show, in addition, is that this interaction can lead to a decrease in information loss. The important point is not simply that an increase in transmission efficiency due to an input-trace interaction can occur. This is obvious in cases involving large input loads. For instance, consider a person listening to a long poem with which he is highly familiar. He could easily reproduce the whole of what was said. If a randomly selected word were changed he would usually notice it and could withhold reproduction. This would demonstrate that when the poem is read correctly he reproduces what he heard, and not what (at the time of reproduction) he guesses himself to have heard. His performance would be very different if the poem was unknown to him, for then he would never give a correct reproduction from a single presentation. The important point made by the results of the present experiment is that input-trace interaction can also produce an increase in transmission efficiency when the input is only one word, and the storage time only a few seconds.

The various phases in which information loss might be reduced are read-out, storage, and use. The next three sections consider each possibility in turn. Two preliminary considerations suggest that reduction in loss at read-out might be the more important. In the first place, there seems to be no information loss during storage in the LFD condition. If there was, performance would be expected to improve with decreases in the interval between target and comparator words. Evidence that this is not the case has already been mentioned (Section 4.2). In the second place, information loss during use, at least in the LFI condition, seems unlikely. Reasons for this view were given earlier.

### 5.4.2 Prior experience and read-out

It was argued at the beginning of this chapter that duration-sensitive performance shows the number of letters read out. This performance has now been shown to vary with the subjects prior experience of the displayed words. Good grounds therefore exist for concluding that read-out varies with word familiarity. Before it can be assumed that this conclusion is established, however, an important objection must be considered. The objection is that there are two aspects of the results that weaken the claim that LFD performance at the short durations shows the number of letters read out. First, the claim was, in part, based on the sensitivity of performance to display duration, and LFD performance was far less sensitive to duration changes than either HFD or LFI performance. Second, LFD performance was worse than LFI performance. This finding will be discussed more fully in Section 5.4.4. Its relevance here is that it strongly indicates, contrary to earlier assumptions, that some information loss in the LFD condition occurs during utilization. The LFI and LFD conditions differ only in the way in which the information is used, and this difference involves a longer storage time in the LFI condition; recognition responses were completed within about 9 seconds in the LFI condition, but within about 3 seconds in the LFD condition. The difference in performance thus indicates that some information loss in the LFD condition occurs during comparison with the comparator word. If this is so then the superiority of HFD over LFD performance might result from a reduction of this loss and not from a reduction of loss during read-out.

The above objection is sound, but it can be met by the comparison of HFD with LFI performance. LFI performance was shown to be highly sensitive to duration and there is no evidence in this case of information loss during utilization. As scoring differs in LFI and HFD conditions it is necessary to consider whether the observed difference between them is merely a scoring artifact. It can be shown mathematically that if whole letters are read out then the two scores are equivalent, but that if only parts of letters are read out the discrimination score will be greater. It might therefore be claimed that read-out in HFD and LFI conditions is the same, but is only of parts of letters, thus producing an apparent difference. There are three good reasons for rejecting this claim:

1. If it were true then LFD performance would be better than LFI performance, but in fact it is worse.

2. There is good evidence that read-out is predominantly in letters, not letter parts. For instance, there is much evidence that read-out involves transformation of the letters into their acoustic equivalents (Conrad, 1964; Sperling, 1963). This could hardly be so if read-out was of letter parts.

3. If the superiority of HFD over LFD performance was due to the differences in scoring it would be independent of letter position, because the scoring differences do not depend upon letter position. It will be shown in Chapter 8 that HFD superiority is in fact highly dependent upon letter position.

The outcome of the above arguments is that experiment 2 provides very strong evidence that the amount read out from a briefly available visual display depends upon the familiarity of the displayed material.

This conclusion, if correct, carries important implications for the nature of information processing in word recognition. It might seem to carry the paradoxical implication that the subject must first 'see' the word in order to know how much of it to 'see'. A similar problem, known as the problem of the pre-perceiver, has of course been much discussed in connection with the phenomena of perceptual defence. Here, the paradox rests upon the widely held assumption that the input is categorized as a particular word only after read-out (see, for instance, Broadbent, 1963). If the word is classified as familiar only after read-out, then how can read-out be affected by word familiarity? The following arguments show that the only possible answer to this question is inadequate to account for the results of the present experiment.

If it is only by the letters read out that the word is categorized as familiar, then familiarity can affect read-out in only one way; and that is by changing the read-out rate of later letters on the basis of the identity of letters read out earlier. For example, read-out rate could increase if letters already read out were part of a familiar word. Now it can be seen that an effect of this kind cannot account for the results of experiment 2. In the first place, HFD read-out is four letters at durations at which LFI read-out is only two letters. If the effect of familiarity were based on the identity of just two letters it would generalize to nearly all words, and thus leave little or no difference between familiar and unfamiliar words. In the second place, with an effect of this kind the difference in performance between familiar and unfamiliar words would increase with the number of letters read out (because this would increase the probability of differentiation between familiar and unfamiliar words). If this were the case the difference between HFD and LFI conditions would increase with duration. But it was seen in the analysis of variance summarized in Table 6 that the condition X duration interaction term did not even approach significance.

On the assumption that word classification occurs only after read-out, therefore, the observed effects of familiarity on read-out are not possible. Thus, if these arguments are correct, the assumption must be wrong, and classification occurs before read-out.

It is important to note that this classification cannot be a matter of differentiating between familiar and unfamiliar words on the basis of limited properties of the input. The familiar and unfamiliar words in this experiment were of homogenous structure, as all were CVCVCVC's. Furthermore, the familiar and unfamiliar words were formed by random sampling from this population of homogeneously structured words. The input must therefore be classified as a particular word, before it can be treated as familiar or not. As all words were printed in capitals this classification cannot be based upon 'general word outline' (see Section 1.2.1), but must involve the use of letter identity.

These considerations show the importance of the distinction between the task of classifying the sensory input and the task of storing information telling which classifications have been made. If read-out is associated with the task of storage and not with the task of classifying, the problem of the pre-perceiver disappears. For sufficiently familiar words the sensory input is classified as a particular word, and that single classification is then read out. For unfamiliar words no ready-made classification is available. Each part of the stimulus is separately classified as a particular letter, and each of these classifications are then read out. Thus, if the amount read out in a given time is limited to a certain number of classifications the information loss due to these limitations will be reduced if read-out is of classifications at the word level.

This interpretation of the dependence of duration-sensitive performance on familiarity has arrived at what is essentially the 'whole-word' theory of Woodworth and James McKeen Cattell (see Section

1.2.1). If the interpretation is valid, the results of experiment 2 show this theory to be correct.

5.4.3 Prior experience and storage

The longest presentation durations in this experiment were included on the grounds that performance at such durations shows storage limitations. Performance at these durations was much better under high than under low familiarity conditions. As stated in the previous section there are grounds for suspecting that some information loss in the LFD condition might occur during utilization. But again the difficulty can be met by comparing HFD and LFI performance; and again this comparison shows performance with highly familiar material to be superior. Experiment 2 therefore indicates that the information loss during storage is less for familiar than for unfamiliar material. This conclusion is in agreement with that of Lachman and Tuttle (1965), who studied the memory of paragraphs approximating English to varying degrees, using a method of 'successive binary recognition'.

If this conclusion is correct it is easily explained by the whole-word theory. The avoidance of storage limitations is a natural consequence of having only one classification to remember. A possible objection to this explanation is that if it were correct HFD performance should rise rapidly to seven letters, which it did not. There are two replies to this objection. First, the levelling-off of HFD performance at less than 7 letters could easily be a ceiling effect; second it is possible that there are other limitations, perhaps in resolution or in read-out processes, which are observable only when storage limitations are removed. Some evidence relevant to these problems is provided by experiment 5, in which HFD performance with higher input loads is studied.

### 5.4.4 The effect of the task on performance

In both LFI and LFD conditions the subject must see and remember as many letters as possible of an unfamiliar word. The conditions differ in that in one case he writes the letters down and in the other he uses them for comparison with another word. LFI performance was superior to LFD performance. For two reasons this is a surprising result:

1. The duration for which information needs to be stored is much less in the LFD condition. The LFD response required, on average, about 3 seconds; the LFI responses required, on average, about 9 seconds.

2. The methods of identification and discrimination used here are very similar to the traditional methods of recall and recognition respectively. Experiments comparing retention using the latter two measures have consistently shown recognition scores to be higher than recall scores (Luh, 1922; Postman and Rau, 1957).

As the LFI and LFD conditions differ predominantly in the way in which the information obtained about the stimulus is used, it seems most likely that the additional loss of information in the LFD condition occurs during the comparison process. It is not easy to see why comparison should cause information loss. However what this result does show is that the perceptual systems cannot be assumed to provide a kind of general purpose information which can be used equally well for any task. The degree to which the task itself causes information loss in addition to that occurring in other ways probably varies greatly from task to task, and might often be negligible. Nevertheless, the LFI-LFD difference certainly urges caution in the interpretation of tachistoscopic experiments.

## 5.5 Summary

The two most important conclusions of experiment 2 were:

1. The number of letters in the stimulus component of word recognition performance depends upon the subject's prior experience of the displayed words. The evidence for this conclusion was the superiority of the HFD performance over LFD performance.

2. The number of letters read out depends upon the subject's prior experience of the displayed words. The evidence for this conclusion was the superiority of duration-

sensitive HFD performance over both LFD and LFI performance. It was argued that this result confirms the 'whole-word' theory of Woodworth and Cattell.

Two subsidiary conclusions were:

1. The number of letters which can be effectively stored until utilization depends upon the subject's prior experience of the displayed words. This conclusion was based on the superiority of HFD performance over both LFI and LFD performance at the longest display durations used. It was noted that this result is easily explained in terms of the 'whole-word' theory.

2. More letters of low familiarity words can be written down than can be used for comparison with another word. It was argued that this probably indicates a loss of stored information during the comparison process, but no further explanation was offered.

# CHAPTER 6

## EXPERIMENT 3: THE DEPENDENCE OF WORD DISCRIMINATION ON THE DURATION OF PRIOR EXPERIENCE AND ON THE KNOWLEDGE OF THE VARIANT WORDS

### 6.1 Introduction

Experiments such as those of Goldiamond and Hawkins (1958) and of Spence (1963), have shown that prior experience affects the supplementary component. Experiment 2 has shown that prior experience affects the stimulus component. However the generality of the two kinds of effects is unknown, and it is still possible that the many phenomena described in Section 1.1 are predominantly due to one kind of effect rather than the other. What is now required is a closer examination of the conditions on which the effects depend.

It was argued earlier that the potentially important differences between experiment 2 and the common types of word recognition situations concern the nature of the prior experience. The optimum readiness established in experiment 2 does occur in other situations but probably not often. The present experiment and the next, therefore, attempt to determine whether effects like those found in experiment 2 can occur with less optimum but more general types of readiness. The present experiment is concerned with two aspects of the prior experience:

its duration, and its content (i.e. the words of which it gives the subject knowledge).

### 6.1.1 The duration of prior experience

The amount of prior experience is clearly of great importance. Research has often shown this to be so, but, surprisingly, the aspect of prior experience whose amount is important has not yet been identified. The amount of prior experience is usually measured in terms of frequency, of which the two major forms are the Thorndike-Lorge frequency, and the experimentally controlled presentation frequency. The relative frequencies with which words occur in popular publications - estimated by Thorndike and Lorge (1944) - is one of the most all-embracing independent variables in psychology. It must be correlated with nearly every aspect of prior experience. Use of the Thorndike-Lorge frequency can show performance to depend on the amount of something, but it cannot show what that something is. Experimentally controlled presentation frequency greatly reduces but does not remove the difficulty. In the first place it is hard to determine what a presentation is, and in the second place no cogent arguments are anywhere presented to support the claim that frequency is the crucial characteristic, rather than the variables with which it tends to be associated. Ammons (1954) has noted that one such variable is total exposure duration. This tends to be associated with frequency, and might a priori be the more important.

If the critical quantitative aspects of prior experience were known, determination of their relation to effects on the stimulus component would completely resolve this part of the generality issue. This is not possible, and the present experiment attempts only to determine whether prior experience can affect the stimulus component when presentation frequency is reduced to 1, and exposure duration to just a few seconds.

The method involved a simple modification of the LFD condition of experiment 2. The required amount of prior experience was achieved by displaying the comparator word before, as well as after, the target word. There were three conditions: the 11 second condition, in which the comparator word was shown for 11 seconds before the brief display; the 1 second condition in which it was shown for 1 second; and the 0 second condition in which it was not shown at all before the brief display.

In the last chapter it was argued that the prior experience given in the HFD condition enabled the input to be recoded in terms of the familiar words before read-out. If this is so it is of great interest to discover the conditions on which this recoding depends. It is of particular importance to determine how familiar the words must be before such recoding is possible, and the present experiment contributes some evidence relevant to this question. It is possible that sufficient familiarity is established once the word is accurately known to the subject. If this were the case, then performance under the 11 second condition would be as good as that under the HFD condition, but performance under the 1 second condition would be worse. This is because 11 seconds is sufficient to establish accurate knowledge but 1 second is not.

### 6.1.2 Knowledge of the variant words

In experiment 2 the subjects learned the variant words in addition to the comparator words. In the present experiment the subjects were given no prior knowledge of the variant words, and it therefore provides a test of the necessity of such knowledge to the effect of prior experience.

This aspect of prior experience is important both with respect to the mechanisms of transmission facilitation, and with respect to their generality. It is relevant to the mechanisms of transmission facilitation because we do not yet know what relations between the input and the familiar word are computed and used. It might be that the input is related to the representation of the familiar word in such a way as to extract only the relation of identity and not the relation of difference. On the other hand it might be that both the relation of identity and the relation of difference are extracted. In other words, it could be that only identity relations are computed and used, or it could be that both identity and difference relations are computed and used. The first possibility implies that prior experience will not affect performance when, as in the present experiment, it provides familiarity only with the comparator words. When both the variant and the comparator words are known, as in the HFD condition, all read-out can be of identity relations; but when, as in the present experiment, only the comparator words are known, read-out must also be of difference relations. Thus, if only identity relations can be computed the effects of prior experience in the present experiment will either be small or absent.

Knowledge of the variant words is relevant to the problem of generality, because knowledge of all the words shown is common but not universal. In addition, knowledge of variants has the consequence that the subject knows that one of the only two letters is possible at each letter position. If this were a necessary condition for the effect of prior experience to occur it would clearly be an important restriction.

## 6.2 Method

### 6.2.1 Outline

Word discrimination under three conditions of prior experience was studied using the method of random changes. In all three conditions the basic display sequence was that used in the LFD condition of experiment 2, and shown diagrammatically in Figure 5, Chapter 4. In the 11 second condition the comparator word was first displayed in the tachistoscope for 11 seconds. At the end of the 11 seconds it was replaced by the noise field. The subject then prepared himself to receive the target word and triggered its display when he was ready. The comparator word returned to the screen 400 milliseconds after the offset of the target word. It remained on the screen for four seconds, during which time the subject said either 'Same' or 'Different'. Five seconds after the offset of the comparator word, the next comparator word appeared on the screen for 11 seconds, and the whole sequence was repeated 10 times. For each discrimination a new comparator word was used. The subjects were requested to learn the comparator word as well as they could during its 11 second presentation but without writing or saying it. In the 1 second condition the comparator word was shown prior to the target word for 1 second, instead of for 11 seconds. In all other respects the display sequence was the same as for the 11 second condition. The 0 second condition differed from the other two only in the omission of any prior presentation of the comparator word. This condition was therefore very much the same as the LFD condition of experiment 2.

To display duration of the target words was always 100 milliseconds. This value was chosen as being the most likely to provide a task of moderate difficulty for all subjects.

### 6.2.2 Design

The performance of 12 subjects was measured under each of the three conditions. The design was therefore a, 3 X 12, factorial design. The control for serial and order effects was very similar to that of experiment 2. Firstly, practice was given prior to the experimental measurements. Secondly, the treatments were given in a counter-balanced order across subjects; each possible order occurred for exactly two subjects. And thirdly, the order in which conditions were presented to each subject, was a triple replication of a balanced design (that is ABCCBA,ABCCBA,ABCCBA).

### 6.2.3 Procedure and instructions

Each subject was tested in a single session. The session began with about 10 minutes practice, in which the subject became acquainted with each of the experimental conditions. Full instructions were given during this practice period. The instruction protocol used was the same as that of experiment 2, except that Sections 5 and 6 were replaced by the following:

> Describe the 0 second, 1 second, and 11 seconds conditions. Ask the subject to learn the comparator words as well as possible during their 1 or 11 seconds presentations. Give at least five trial runs under each condition.

For the experimental measurements, 10 trials were given under the first condition, 10 under the second, and 10 under the third. The order of the conditions was then reversed and another three blocks of 10 discriminations made. This whole procedure was repeated three times, providing 60 discriminations under each condition for each subject. Each subject therefore saw 180 different pairs of words. The same 180 pairs of words were used for all subjects, each word occurring under each condition for exactly four subjects. After each set of 30 discriminations the subject was told how many were correct out of the 30, but was not told on which trials the errors had occurred.

### 6.2.4 Subjects

The subjects were 12 psychology undergraduates acting as unpaid subjects to fulfil part of their course requirements. Their ages ranged from 16 to 28 years. Seven were female and five were male. None had been used in the previous experiments.

## 6.3 Results

The total numbers of correct and incorrect responses for each subject and condition are given in Table 1 Appendix 3. The separate totals for 'same' and 'different' trials are given in Tables 2 and 3 of Appendix 3. These results are analyzed in terms of the z scores and in terms of the proportions of correct responses.

6.3.1 Letter discrimination scores

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

TABLE 1: LETTER DISCRIMINATION PERFORMANCE

| | PRIOR EXPERIENCE OF COMPARATOR WORD (in seconds) | | |
|---|---|---|---|
| | 0 | 1 | 11 |
| SUBJECT | | | |
| 1. | 3.4 | 4.7 | 5.5 |
| 2. | 3.2 | 3.2 | 2.4 |
| 3. | 2.8 | 3.2 | 3.1 |
| 4. | 1.7 | 4.4 | .8 |
| 5. | 3.6 | 4.1 | 4.5 |
| 6. | .6 | 3.6 | 4.0 |
| 7. | 6.2 | 7.0 | 6.1 |
| 8. | 3.3 | 4.1 | 3.9 |
| 9. | 4.0 | 5.0 | 4.1 |
| 10. | 2.9 | 3.9 | 2.1 |
| 11. | 2.7 | 2.2 | 0.0 |
| 12. | 3.2 | 5.1 | 4.4 |
| MEANS | 3.1 | 4.2 | 3.4 |

Letter discrimination scores averaged over all subjects and conditions was 3.6 letters, which is about half of the word. No subject scored 0 or 7 under all conditions. Together these results indicate that a 100 milliseconds duration for the brief display is an acceptable value for the testing of groups of individuals at a single duration.

A two way analysis of variance was performed on the letter discrimination scores. The results of this analysis are summarized 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 |
|---|---|---|---|---|---|
| Learning Time | 7.49 | 2 | 3.75 | 4.4 | <.05 |
| Subjects | 52.82 | 11 | 4.80 | | |
| Learning Time X Subjects | 18.64 | 22 | .85 | | |
| Total | 78.95 | 35 | | | |

The significance of the conditions effect justifies a more detailed analysis. The critical difference for comparisons between individual means, calculated in the manner described by Lindquist (1935, p.164-166), is .78 letters. Using this value it can be seen from the mean z scores given in Table 1 that the number of letters discriminated is significantly raised by 1 second of prior experience, but not by 11 seconds of prior experience, and that it is significantly greater under the 1 second than under the 11 second condition.

As only a single brief duration was used, these results do not show directly how the improvement under the 1 second condition was divided between duration-sensitive and duration-insensitive performance. However, an indication may be obtained by comparing the results of the subjects scoring least under the 0 second condition with those scoring most. For those scoring least, performance is more likely to be at the duration-sensitive stage, and for those scoring most it is more likely to be at the duration-insensitive stage. The subjects were therefore divided into two groups according to whether they scored above or below the mean on the 0 second condition. The means for those two groups under the 0 second and 1 second condition are shown in Table 3. Dividing the results in this fashion confounds poorer subjects with duration-sensitive performance. The difference between the two groups may thus be due to a greater effect of prior experience with poorer subjects. This, however, is unlikely in view of the fact that experiment 2 found subject x condition interaction to be small and insignificant.

TABLE 3: MEAN LETTER DISCRIMINATION PERFORMANCE

| | PRIOR EXPERIENCE IN SECONDS | |
|---|---|---|
| | 0 | 1 |
| Subjects scoring below mean on 0 second condition | 2.1 | 3.5 |
| Subjects scoring above mean on 0 second condition | 3.8 | 4.7 |

These results therefore suggest that the effect of 1 seconds prior experience is at least as great on duration-sensitive performance as it is on duration-insensitive performance.

### 6.3.2 Numbers and proportions of correct and incorrect responses

Table 4 shows the numbers of correct and incorrect responses summed over 12 subjects for each condition, and Table 5 the proportion of correct responses.

TABLE 4: NUMBERS OF CORRECT AND INCORRECT RESPONSES (SUMMED OVER ALL SUBJECTS)

| | PRIOR EXPERIENCE OF BASIC DISPLAY IN SECONDS | | | | | |
|---|---|---|---|---|---|---|
| | 0 | | 1 | | 11 | |
| | Correct | In-correct | Correct | In-correct | Correct | In-correct |
| 'different' trials | 186 | 118 | 202 | 102 | 171 | 133 |
| 'same' trials | 240 | 104 | 294 | 50 | 296 | 48 |
| Total | 426 | 222 | 496 | 152 | 467 | 181 |

TABLE 5: PROPORTIONS OF CORRECT RESPONSE (ALL SUBJECTS COMBINED)

| | PRIOR EXPERIENCE IN SECONDS | | |
|---|---|---|---|
| | 0 | 1 | 11 |
| 'different' trials | .612 | .664 | .563 |
| | ←(>.1)→ (0 vs 1) | ←(<.01)→ (1 vs 11) | ←(>.1)→ (0 vs 11) |
| 'same' trials | .698 | .855 | .860 |
| | ←(<.01)→ (0 vs 1) | ←(>.1)→ (1 vs 11) | ←(<.01)→ (0 vs 11) |

The values in brackets in Table 5 are the probabilities that the indicated differences would occur by chance (calculated using the Normal approximation to the Binomial distribution). This analysis confirms the conclusion that 1 second or prior experience increased the number of letters discriminated. In addition, it shows that although 11 seconds of prior experience may not have increased the number of letters discriminated it did affect performance by raising q (the probability that the subject says 'Same' on 'same' trials). This did not lead to a significant increase in the value of z, however, because the probability s also increased.

## 6.4 Discussion

This experiment was concerned with the generality of the effect of prior experience on the stimulus component. The primary aim was to discover whether a great deal of learning, and a knowledge of the variant words, are essential to the effect. The results show that neither are necessary. However, as the effect did not occur in the 11 second condition the results are most equivocal with regard to its generality. Together, the results of experiment 2 and 3, suggest the possibility that prior experience will not affect the stimulus component if it makes the subject highly familiar with the comparator words but not with the variants. As prior experience of this kind is very common, this possibility was investigated by experiment 4, which is reported in the next chapter. Further discussion of the generality issue is therefore postponed until the results of this investigation have been described.

The remainder of this discussion deals with a number of subsidiary issues arising from the results of the present experiment.

Better performance after 1 second than after 11 seconds of prior experience is a surprising result. Unless it is replicated, no extensive theoretical inference should be drawn from it. The surprising nature of this result may be reduced, however, when it is noticed that performance under the two conditions would give rise to nearly equal thresholds scores. Threshold measurements depend only upon q (i.e. upon the probability that the subject says the learned word when the learned word is displayed). These two probabilities were very nearly equal - .855 after 1 second and .860 after 11 seconds - so threshold measures would also be very nearly equal. The difference in the z scores tells us that the equality thresholds would show is only apparent, and results from higher guessing rates in the 11 second condition, and higher letter discrimination rates in the 1 second condition.

This result emphasizes the difficulty of interpreting experiments which do not separate stimulus and supplementary components. For instance, Mooney (1958) studied the recognition of complex novel visual configurations after varying amounts of prior experience. Recognition scores obtained after 10 seconds of prior visual exposure to the shape were found to be the same as those obtained after less than 1 second of prior exposure.

Mooney assumed that the equality indicated equality of stimulus discrimination. He concluded that the perceptual learning concerned with novel visual configurations was independent of exposure duration. This conclusion is unjustified, however, because the recognition scores used allowed no adequate correction for guessing. Mooney's experiment and the present one are similar in that both find equality of uncorrected recognition scores after short and long periods of prior exposure. The results of the present experiment, however, show that this cannot be assumed to indicate equality of stimulus discrimination.

It is not known why the 11 second condition failed to increase letter discrimination performance. Of the many possible explanations only three will be mentioned. First, there is the possibility that the result was an artifact of the experimental procedure. It might be that looking at a word for 11 seconds results in some temporary fatigue which reduces performance in the following few seconds. But as all conditions were well interspersed this possibility seems unlikely. It is also unlikely in view of the fact that, in all conditions, the subjects themselves triggered the brief display when they felt that they were ready. Second, because the frequency of the response 'Same', on 'different' trials, increased with learning duration the result might be described as due to an increase in the competitive properties of the comparator word. This explanation predicts that an increase in learning durations beyond 11 seconds would either worsen performance or not affect it. A test of this prediction is provided by experiment 4. Finally, there is a possibility arising out of the claim, made by some subjects, that the 1 second condition is easier than the 11 second condition, because, being of short duration, the prior exposure is more like the brief display, and thus is easier to discriminate from it. This suggests that some visual processing, changing the appearance of the display in subtle ways, may take longer than a second. The possibility that practice with brief displays is better for the discrimination of brief displays is therefore an interesting one, and merits further investigation.

The results also suggest that the crucial quantitative aspect of prior experience is neither presentation frequency nor exposure duration. If frequency were the crucial aspect, the 1 second and 11 second conditions should produce the same performance, as in both cases the presentation frequency is 1. If duration were the crucial aspect an increase in duration would not be expected to produce a decrease in performance.

One thing is made clear by the failure of 11 seconds of prior experience to raise performance above the 0 second condition; knowing the comparator word, and being ready to use it, are not sufficient to reduce information loss during transmission. This is an important result. It shows that the superior performance in the HFD condition of experiment 2 is not simply due to the subject knowing the comparator word and being ready to use it, but to processes of development by prior experience that extend beyond the formation of accurate representations.

# 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 $2 \times 10^7$ 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 $2 \times 10^7$ 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 $2 \times 10^7$ 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 | | |
|---|---|---|---|
| | $2 \times 10^7$ | 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 $2 \times 10^7$ 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 X $10^7$ 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 X $10^7$ | 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 X $10^7$ condition more than that of subjects discriminating 5 letters on the 2 X $10^7$ 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 | | | | | |
|---|---|---|---|---|---|---|
| | $2 \times 10^7$ | | 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 | | |
|---|---|---|---|
| | $2 \times 10^7$ | 4 | 1 |
| 'Different' trials | .655 | .748 | .783 |
| | ←(< .05)→ | | |
| | | ←(> .3)→ | |
| | ←(< .01)→ | | |
| 'Same' trials | .693 | .846 | .912 |
| | ←(< .01)→ | | |
| | | ←(< .05)→ | |
| | ←(≪ .01)→ | | |

With respect to the comparison between the $2 \times 10^7$ 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 post-exposure 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 <u>after</u> the word has been presented as Heron suggests. This can only be the case, however, if the display scanned is <u>not</u> 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 <u>general visual storage and erasure</u>, and <u>special visual storage and erasure</u>. 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 <u>inter-stimulus interval</u>, 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 $2 \times 10^7$ 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, $\emptyset$, 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 $\emptyset$ 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 $\emptyset$ were used and sampling errors were not taken into account. These estimates were however based on very large samples. Furthermore, because $\emptyset$ 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.

| SUBJECT | REHEARSAL FREQUENCY | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | | 10 | | 5 | | 2 | | 1 | |
| | 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 |

(continued on next page)

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.

| SUBJECT | PRIOR EXPERIENCE OF COMPARATOR WORD (SECONDS) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | | 1 | | 11 | |
| | 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 | | 1 | | 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 | | | | | |
|---|---|---|---|---|---|---|
| | $2 \times 10^7$ | | 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 | | | | | |
|---|---|---|---|---|---|---|
| | $2 \times 10^7$ | | 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.

| | NUMBER OF ALTERNATIVE COMPARATOR WORDS | | | | | |
|---|---|---|---|---|---|---|
| | $2 \times 10^7$ | | 4 | | 1 | |
| SUBJECT | 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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