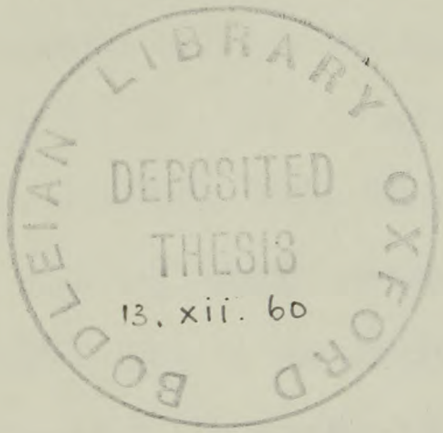
STUDIES OF SELECTIVE LISTENING

by

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Thesis submitted at the University of Oxford for the degree of Doctor of Philosophy. 1960.

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Studies of Selective Listening, by N. Moray.

Cherry (1953) discovered that if a subject listens to a passage of prose presented to one ear and repeats it aloud, he remains ignorant of the content, though not of the general characteristics, of another, different prose passage presented simultaneously to his other ear. The present thesis examines the nature of this selective blocking of content in selective dichotic listening, suggests a model for the mechanisms involved, discusses the relations between this and other "kinds" of attention, and speculates on the neurophysiological mechanisms involved.

Using Cherry's original technique it is shown that even if the rejected message is a list of seven words repeated 35 times it leaves no detectable trace (Chapter II). Certain stimuli can break down this block, however, and these seem to be "important" stimuli such as the subject's own name. An attempt to make a word "important" by pairing it with electric shock is described, with another attempt to change the affective value of stimuli by giving the subject instructions to alter his "set". The first of these attempts was successful, (Chapter IV). The block appears to be extraordinarily effective, since the subject's attention does not switch even when there is a considerable disparity in loudness between the two messages (Chapter III).

A review is given of some of the recent work on selective listening, and on the basis of this a model is suggested for the

mechanisms which underlie the observed phenomena.

The model supposes that the input from either ear is treated in two ways. One pathway from the ear to perceptual mechanisms treats words simply as sounds, and this pathway is not blocked in selective dichotic listening. But there is a second pathway, which leads to the higher analytical mechanisms which treat sounds as words, and in selective listening this pathway may be blocked below the level of conscious perception. The signals passing into the central nervous system are sampled by a localisation device, which compares the two inputs and takes a decision as to whether one or more messages are present and where they are localised. The subject's voluntary decision to listen to one ear and not the other "biasses" the system towards accepting signals along one input pathway rather than the other, unless the localisation device decides there is only one message present in a position which renders the voluntary selection impossible. The brain receives the early parts of the message, and on the basis of past experience of the transitional probabilities between the signals of a language, it predicts what signals are likely to appear later in the message. Whichever input channel receives a message which most nearly matches these predictions will tend to be accepted, (Chapter III). Modifications of this basic model are suggested to deal with the role of "important" signals, and situations involving more than two messages (Chapter IV).

Various experiments to test the model are described,

such as one in which the transitional probabilities between signals are varied by using statistical approximations to English. Further, if the same message is sent to the two ears, but with a large time difference between the arrival of a given word at the two ears, the subject does not realise that they are the same message if he listens to one of them. If he listens to, and repeats, the one which leads in time he realises that they are the same (his attention breaks down) when the two messages are as much as six or more seconds apart. If he listens to the one which lags in time this only happens when the messages are less than 1½ seconds apart. The difference is shown not to be an artifact of the time taken to repeat what is heard, which takes only about 1 second. The difference would be predicted by the model, and is related to it in discussion. Other data from the review are also related to the model.

Two phenomena which bear on the general problem of selective listening are discussed - the time taken to switch attention, and the apparent diversity of the "kinds" of attention.

The failure to break down the subject's attention by "setting" him with instructions raised the question of switching time, for one of the conditions used in that experiment was such that the estimate of switching time of attention made by Broadbent (1954), and similar work by the writer, should have allowed the subject ample time to switch to that message for which he was set. An experiment is described which produces results which differ from Broadbent's as regards switching time, and which cast doubt on his "Filter Theory" model. He has suggested that there is a

very short term memory store peripheral to a filter which can select one of the possible channels through which signals enter the nervous system, but the data here presented show that the effect of the rate of presentation upon recall of stimuli in an immediate memory experiment is not such as would support Broadbent's model. A critique of the rationale of experiments on switching time is given, pointing out that the present experimental designs are inadequate to ensure that the subject is indeed switching, (Chapter V).

The way in which the concept of attention has been used in modern experimental psychology is reviewed, and four apparently distinct uses are described. Firstly there is the "mentalistic" use of the early experimental psychologists, such as Wundt and Titchener. Secondly, there is the use in vigilance experiments, which seem best described as a prolonged task of signal/noise discrimination. Thirdly, there is the use such as is found in the present thesis, where attention refers to the selection of one from a number of possible channels along which signals may arrive. Lastly, there is the use in the sense of "mental concentration." Titchener's list of attention-catching stimuli is compared with the results found in selective dichotic listening. It is suggested that it would be both useful and possible to enquire whether separate mechanisms underlie these different uses of the concept of attention, and a start is made in this direction by showing that there is no significant correlation between scores on a test of concentration and scores on a listening-and-repeating situation (Chapter VI).

In considering the neurophysiology of these phenomena the evidence about four parts of the mechanism is assessed. Firstly evidence is brought from ablation studies in animals and dysphasia in humans to show that the meaning-analysis mechanisms of the brain can be affected without affecting those responsible for comparatively crude discriminations. For example in word deafness aphasia there is little or no loss in auditory sensitivity as measured with an audiometer, but the meaning of words and tunes is utterly lost. Secondly, the position of the auditory localisation mechanisms is considered, and that for comparing the early and later parts of messages received. It is tentatively concluded that the auditory localisation mechanisms are located in the olivary nuclei of the trapezoid body; and that a pathway from the parieto-temporal area of the cortex which is brought into relation with the afferent inflow by way of a circuit involving the reticular formation may be the mechanism of the prediction devices. Thirdly, the level of the block for meaning is discussed. On the basis of ablation studies in animals, GSR conditioning experiments in the awake human, and EEG studies of the ability of the sleeping human to discriminate between signals, it is suggested that the block lies between the auditory cortex and the reticular formation. Lastly, the question of the way in which "switching" of the attention is brought about is discussed. It is tentatively suggested that the initial "biassing" of the system is through a fronto-reticular pathway, and that the reticular formation is probably the centre of the system, where the several factors responsible for producing the particular response observed

on any given occasion interact to produce the final result, (Chapter VII).

In a final chapter a recapitulation of the model is given, together with a brief discussion of the writer's attitude to models in general. The present thesis is considered as a preliminary progress report on work in a field which seems to be as yet untouched except by the writer and Taylor (1960). Points of particular interest are noted, and a programme of research using both behavioural and neurophysiological techniques is indicated.

CONTENTS

Chapter I
Introduction p. 1

Chapter II
Introductory Experiments p. 6

Chapter III
Selective Listening: Surveys and Suggestions p. 16

Chapter IV
Complex Variables in Selective Listening p. 81

Chapter V
Questions of Timing and Switching of Attention p. 113

Chapter VI
The Nature of "Attention" in Selective Listening p. 142

Chpater VII
The Neurophysiology of Selective Listening p. 166

Chapter VIII
Conclusions and Prospects. p. 191

Acknowledgements p. 199

Bibliography p. 202

CHAPTER I

INTRODUCTION

"The discovery of a reliable measure of the attention would appear to be one of the most important problems that await solution by the experimental psychology of the future."

(O. Kulpe., Outlines of Psychology., 1895)

From the beginnings of modern experimental psychology there has been a continual interest in the problem of attention. At times it has been involved in the various philosophical disputes of mechanists and the proponents of free-will, at times it appears as the object of ingenious designs in speculative neurology, often under a wide variety of names, all purporting to answer the question, "What is attention?".

The present writer does not intend to add yet another entry to the catalogue: indeed in a later chapter he will maintain that such an attempt is bound to end in futility, since the use of the term is so varied, that the concept can never be tied down. There is, in fact, no single answer to the question posed at the end of the preceeding paragraph.

At the same time, it is true that there are a wide variety of phenomena which are of great interest to the student of behaviour, and which, for all their diversity, in everyday use are described by the term "attention". This thesis is concerned with a small subclass of these.

Attempts to measure attention have a respectable history, or at least a lengthy one, in the annals of experimental psychology. Jevons, James, Wundt, and Titchner among the great figures of the past, Hebb, Broadbent, and Cherry among the moderns. Not in all cases would the workers describe their own work as being concerned with attention, but there is no doubt that the man in the street, hearing the work reported, would so describe it, whether the problem was the possibility of doing two things at once, listening to one thing and ignoring another, or concentrating upon a tracking task or the detection of a change in the position of a large number of dials.

From these we will be concerned with such experiments as bear on the problems of selective listening. The questions which will occupy us will be such as, How do we listen to one out of several voices speaking simultaneously? How efficiently can we disregard a message received by one ear when paying attention to the other? What are the cues and mechanisms which allow us to do this? How fast do we switch attention from one ear to the other? and, What are the neurological mechanisms which underly these types of behaviour?

Historically, the last ten years have seen the beginnings of what may well be regarded as the Golden Age of research upon attention. One of the problems which has always bedevilled such work has been that of presenting the stimulus. In vision the stereoscope has long been in use, (although there are several strong objections to its use on these problems), together with tachistoscopes, reversible figures, inkblots, and all the customary paraphenalia which go to make up an experiment on "set", "attention",

or whatever the particular worker feels inclined to call it. Hearing, however, has been rather the Cinderella of attentional research, left sitting alone in a soundproof room, with the meagre stimuli of pure tones, clicks, and other easily massproduced signals to amuse herself; while her sisters enjoy the lights and colours of the visual perception laboratory. Sound stimuli, with the characteristic of having forms of which the most interesting always have a long duration, have been difficult to handle in the laboratory, especially those which are par excellence typical of human behaviour, namely speech signals. And even the advent of gramaphone records did not bring much solace to the experimenter desperately trying to standardise and repeat his stimuli. The 1939 - 1945 war, however, saw the development of the tape recorder, with its easily removeable and recordable messages, and enormous potentialities of development; and since its appearance, the acceleration of auditory research, in the field of speech in particular, has been enormous.

The new research in selective listening also soon brought to light a particularly interesting phenomenon. Cherry (1953), adapting a technique of Licklider's, investigated the responses of subjects to dichotic speech stimulation. That is, he presented one message to one of the subject's ears, and another, different, one simultaneously to the other ear. But he added a new experimental detail: the subject now had to repeat out loud what he heard through the ear to which he was attending. This he could do, but could then say nothing about the content of the rejected message, although he could give a rather vague report about its general properties.

(This experiment is reported in more detail in the next chapter). Cherry did not follow up this particular finding. But it appeared to be the answer to the search which Kulpe spoke of in the quotation at the head of this chapter. Here was an easily manipulable experimental technique; and here also, it seemed, was a way of being sure that the subject was paying attention to what he was told to pay attention to: it was merely necessary to estimate the mistakes made in reporting the accepted message, and the number, type, etc., of the words from the rejected message which appeared despite his efforts in his response. For once

"... the time and the place
And the loved one ...."

were all together. This thesis is the result of the happy conjunction. The author hopes that it has been a fruitful marriage.

Although, as said above, it is not intended to give a final definition of what attention really is, at least some form of operational definition is needed in the context of which the word will be used. It is unfortunately the case that so wide is the current and past use of the word "attention", that even such a definition is extremely difficult if precision is required. A natural way to speak is in terms of phrases such as ".. a lowering of the threshold for a particular stimulus at the expense of the thresholds for all other stimuli..." or some such phrase. But even this will not do, for Ingham (1957) has reported a result which would be excluded and yet which is certainly an experiment on attention, (see below, P.150). But since a definition is necessary,

it will be achieved thus:

An estimate of whether the subject could pay attention (listen selectively) to a given stimulus or class of stimuli will be based on experiments whose design is similar to the following:

1. The subject is told,

   "Listen to (your right ear, the first voice that speaks, etc.) and ignore (your left ear, the other voices, etc.) which are an attempt to distract you."

2. Conditions of response (e.g. time elapsed before recall, etc.,) are held constant for different stimulus conditions, or allowed to vary in a way previously shown to be unimportant.

3. The statement "S could/could not pay attention to the stimulus" will be decided on an objective score in terms of number of words correctly reported from the accepted message, number of words imported from the rejected message, etc.

Although the title of the investigation is "studies in selective listening", the word "attention" will be used throughout as synonymous with "selective listening", and "paying attention" with "listening selectively": that is, the use of the word will tend to the colloquial - a comparatively (perhaps unfortunately) rare event in psychological terminology.

C H A P T E R II

INTRODUCTORY EXPERIMENTS

"....hearing they hear not,
neither do they understand"
(St. Matthew, XIII, 13).

The studies to be described in these pages arose originally from an attempt to do research in a field rather far removed from two-channel listening and speech shadowing, namely the elusive problem of Reminiscence in short term memory. This phenomenon, an improvement in recall score after a period in which a subject has had no practice, had been reported by Ballard (1913), English, Welborn and Killiam (1934) and Ward (1937); and attacked by - among others - McGeoch (1935) on the grounds that the controls were insufficient, and that changes of set, and slight moment to moment variations in the experimental situation could sufficiently account for the observed facts without the invoking of a new function. Ward's study is probably the best controlled. Well aware that the major problem in such research is to ensure that there is no rehearsal, either voluntary or involuntary, on the part of the subjects during the time between presentation and testing, Ward tried to keep his subjects occupied with standard tasks during this interval; and came out with clear cut evidence of improvement in the subjects'

scores during a period of up to three minutes after the presentation had finished. Although this study was well-controlled, research in the field has languished, probably due to a feeling that it is virtually impossible to make certain that the subject does not rehearse, and that all other experimental variables are held sufficiently constant to ensure that the result is not an artifact.

But if the fact of reminiscence could be established, it would be of great interest for the development of memory theories, since with the discovery of the facilitation of nervous pathways with use, and the introduction of the concept of reverberating circuits as possible short term memory stores, the time course of such a phenomenon might be most important, as also of course it would be for any "fading trace" theory of memory.

Cherry (1953) reported work which suggested that a suitable experimental technique might have been found. He presented prose passages dichotically to subjects, and required them to "shadow" one. That is, the subject heard a message through, for example, his right ear which he had to repeat out loud at the same time as listening to it, while disregarding another, different, message to his left ear. He reported that this task could be done fairly easily and that there was little interference from the rejected message. Merely as an example of the efficiency of directed attention this would have been of interest, but the subjects' reports about the rejected message were even more so. They could say afterwards whether it had been

speech or noise, whether the voice had changed from a man's to a woman's; whether there had been a sudden signal in an otherwise quiet message. But they could report nothing of the verbal content of the message at all. The speaker could change from one language to another and back and the change would not be noticed, and if the subjects were asked what the passage was about, or to give any, even isolated, words from it, they could not.

Now since something, at least information about the gross physical characteristics of the message, was entering the subject's memory, it looked as if this might be a way to study reminiscence. If the rejected message consisted of continuous prose, it was asking the subjects quite a lot to recall items from it, for they heard them only once, and except for situations like tests of immediate memory span and cases where "memoire affective" may operate, it is rare that a single presentation of a signal leads to its being remembered, especially if it is one of a series of similar ones and anyway the subject's attention is diverted elsewhere! But if reminiscence were due to some property of the nervous system and did not require the co-operation of the subject by rehearsal, then a short list of words presented to one of his ears repeatedly while he shadowed a message to the other ear might be remembered, and the time course of reminiscence followed. Moreover, since the subject seemed not to notice the content of the message during shadowing, and anyway was fully occupied by the shadowing task, he could not rehearse it.

With this idea, the following modification of Cherry's original experiment was designed.

Experiment 1

Subjects were given practice at shadowing one of a pair of dichotic passages of prose, using four short passages, and alternating between that given to the left and right ear as the accepted message. They were then required to shadow a long passage of prose, a descriptive passage taken from a light novel, while the rejected message consisted of a list of seven words repeated 35 times.

Three lists of seven single syllable nouns were prepared. List I was made up of the nearest single syllable noun to every 150th word of the prose passage, with the provise that none were repeated. The other two lists were obtained thus: 22 single syllable nouns were picked at random from other parts of the same novel and were then given in two lists of 11 words each to 10 subjects (not those used in the experiment proper) to whom the prose passage was read. They were then asked to rank the words in order of fittingness to be in the passage. The same 10 subjects were then given List I and asked to say which of the other words they associated with words in List I. Those words with particularly strong associations were removed from the final lists.

It was hoped by these two procedures to eliminate to some degree artifacts due to the nature of the stimuli being used, that is, too high a score due to association, or too low a score due to subjects

rejecting words which they might have heard because they thought that they could not possibly have occurred. From the 22 words, with allowance for these two tests, were selected two lists of seven each, roughly matched for "fittingness" and association. These were called Lists II and III. List II was repeated 35 times as the rejected message, while List III served as the control in the recognition test. The three lists are given below.

Table I

Lists of Words Used in the Recognition Tests

List I	List II	List III
Streaks	Sound	Moon
Face	Force	Coast
Days	Ghost	Raft
World	Task	Help
Crest	Trap	Reed
Quilt	Road	Trail
Scale	Proof	Glass

None of the words in Lists II and III were present in the prose passage, which was taken from "Perelandra", by C.S. Lewis, Pan Books Ed. p.27. The words were printed out on 2" x 2" cards, and their order randomised for use in the recognition test.

After the practice runs, the subjects were told that in the experiment proper their response was to be recorded, and the number of mistakes they made analysed; and furthermore that after the passage

had ended they would be asked questions about its content. It was impressed on them that the "rejected" message was being used to measure the effect of distraction on their recall performance, and they were not to switch to the wrong message during the passage. It was hoped that these instructions would give the subjects a "set" for remembering the passage while at the same time ensuring that they would follow the accepted passage throughout the experiment. They then shadowed the prose passage. The list of words was faded in after they had begun shadowing until it was approximately of equal intensity to the prose passage. (An attempt was made to measure threshold accurately, but this was found impracticable, and Cherry had found (personal communication) that the loudness of the two messages was not very critical for these studies. At the end of the passage List II finished about two seconds before the prose passage. Immediately the prose passage finished the subject was asked if he could remember anything from the rejected message, and prompted hard to do so. His answers were noted and he was then given the following recognition test, the time gap between the end of the last presentation of List II and the start of the recognition test being about 30 seconds.

The experimenter sat opposite the subject and dealt the randomised cards with the words from the three lists face up one by one in front of the subject. The latter read each word out loud, and then said "yes" or "no" according to whether he thought he had heard the word or not. It was urged that he was to say "Yes" if he thought it had

been in the rejected passage as well as if he thought it had been in the accepted passage, and also if he was unsure as to which message it came from but thought that he had heard it.

The pooled results for eight subjects were analysed by calculating the mean number of correct recognitions per list, and submitting the differences to a t-test. The results are shown in Table II.

Table II

Recognition scores from Shadowed, Rejected and Control Lists

	Mean Words Recognised.
a. Words presented in shadowed message (List I)	4.9 out of 7
b. Words presented in rejected message (List II)	1.9 out of 7
c. Words presented in recognition tesf for the first time (List III)	2.6 out of 6

The difference between a and b is significant at the 1 per cent level
The difference between b and c is not significant.

These results confirm Cherry's (1953) findings in a rather more rigorous setting. There seems to be very little information indeed recalled from the rejected message.

Several points of interest emerged from the introspections offered by the subjects. They found the task quite easy to do once they

had got started, but also found it extremely dull. They made few mistakes in shadowing. Part of the dullness of the task may have been due to the recording having been in a monotone, for throughout the experiments to be described this is a recurring complaint of the subjects taking part. The recording was done in this way to minimise the effects of variations in loudness of the speech, as it was thought that a sudden relatively quiet period in the shadowed message might allow signals from the opposite ear to capture the attention during the "gap", and it was desired to avoid this. As Cherry reported, the voices in which the subjects responded tended to be also very monotonous and indeed one subject remarked that she had almost gone into a trance state, and that "half way through everything in front of my eyes just started to go blank." Her performance at this point, while not as good as most, fell off only a little. It would seem from this that although the situation is one in which it is certainly true to say that the subject is required to pay attention to a very specific message in the presence of a competing stimulus, it is also a situation where it is difficult to maintain a high level of vigilance. Later this question of the relation between the difference between the various sorts of "attention" will appear again in connexion with other experiments and in the discussion of the neurology of the phenomena observed. At the same time, there was no tendency apparent to recognise only those words which came towards the end of the accepted message, so that what was heard was retained fairly well.

It might be objected that the gap of 30 secs. between the end of the shadowing and the beginning of the recognition test was the cause why so little was recognised. But there are several reasons why this is unlikely to be the whole story. For one thing, that time was occupied by strenuous efforts on the part of the subject to recall the rejected message, and what he did recall was the same as Cherry found; namely, any rather gross characteristics of the physical stimulus, such as speech-not-tone, man's voice, etc. Secondly, if the account of Reminiscence is correct, and if the material had reached a short term memory store, according to Ward (1957) we might expect recognition actually to improve after this period. Finally, one or two introspections are relevant. Two of the subjects could say that the rejected message consisted of a list of words rather than a prose passage, and these two also did report definitely hearing one word from the rejected message. That was "ghost" and they remarked that they had heard it at a moment when the speaker of the prose passage was taking a breath, that is, when there was a momentary silent gap in the accepted message. They did not know at that time that they would be asked anything about the rejected message, but they did recall the word afterwards, evidence that there is no reason to say that the only reason for the low recognition score for the rejected message is the lapse of 30 seconds between presentation and testing.

It is clear from these results that as a direct technique for investigating Reminiscence the use of dichotic shadowing in this way

is a failure. It might be possible to show some effect of the rejected message using a relearning technique, although in the light of other experiments to be reported here, (in particular Expt. (7) and Expt. (9)), it is very unlikely. The block set up in this task by the subject's decision to pay attention to a particular ear is very efficient, and seems to be on the peripheral side of any memory store, at least as far as the recognition of words goes. When once this is said, it will be seen that studies are immediately relevant to such theories as the "Filter Theory" of Broadbent (1958), especially as the block does let through something, and seems to function more as a selective filter than as an all-or-none switch.

Several obvious questions spring to mind in the light of this. What is the limit of the efficiency of the block? Under what conditions does it break down? Just how much does get past it? This thesis will be an attempt to answer some of these questions, and to provide a logical model with an eye to further research.

CHAPTER III

SELECTIVE LISTENING : SURVEYS AND SUGGESTIONS

Any attempt to construct a model to describe the mechanisms of selective listening must be preceded by a review of the relevant experimental data, and this chapter will begin with such a review. The range of experiments covered will include not only those on shadowing but also cases of selective listening to one of several simultaneous messages presented binaurally or monaurally. The first part of the review will be concerned with what will be called "raw data" variables; that is, such qualities as the amplitude, frequency, and time characteristics of messages considered simply as waves. Later the properties of messages as speech rather than merely sound will be considered, that is, the messages will be considered as Markov chain sequences of signals, with properties conveyed by the transitional probabilities between individual signals. The review is not intended to be exhaustive, since an extensive survey has recently been published by Broadbent (1958), but will cite data and report new experiments only where relevant to the two questions,

1. Under what conditions can a subject listen to one of two or more simultaneous messages,? and

2. Under what conditions is this impossible?

The implications of the answers to these questions will be discussed, and finally a model will be suggested for predicting selective

listening behaviour in terms of the similarity or dissimilarity of messages with respect to certain parameters.

1. Conditions where the subject can listen selectively to one message in the presence of one or more competing messages

A. Dichotic presentation, pitch and intensity of messages the same, message content different . . . . . p. 17
B. Monaural or binaural presentation, pitch and intensity the same, message content different. . . . . p. 22
C. Dichotic presentation, pitch of message the same, intensity and message content different . . . . p. 24
D. Dichotic presentation, message content, pitch, and intensity the same, timing different. . . . . p. 32
E. Monaural or binaural presentation, two message contents the same, timing different . . . . . p. 39

2. Conditions where it is impossible for a subject to listen selectively to one of two or more simultaneous messages

A. Intensity, pitch and message content the same, timing different . . . . . p. 40
B. Binaural presentation, message content the same, and different intensity at each ear . . . . . p. 40
C. Binaural presentation, message content the same and intensity the same to each ear, pitch different . . p. 41

1.A Dichotic presentation, pitch and intensity of messages the same, message content different

We have already seen, both from Cherry's earlier work and the experiment described in the previous chapter, that in a dichotic shadowing situation a subject can select one of the messages and ignore the other. Moreover the efficiency of this block is quite remarkable, at least as far as the actual verbal content of the message is concerned.

Let us look more closely at just what does get past the block which holds back the rejected message.

Cherry (1953) presented several sorts of rejected message to the subject while the latter shadowed normal English prose on the opposite ear. The results can be summarised in a table, thus:-

TABLE III

Accepted message	Rejected message			Result
Normal English prose	Normal English prose			
	N.E.P.	- N.E.P. female voice	- N.E.P.	+
	"	- reversed speech	- "	-
	"	- foreign language	- "	-
	"	- 400 c.p.s.	- "	+

That is, as well as playing a whole prose passage spoken by one speaker as the rejected message, he also used conditions in which the rejected message began and ended as normal English prose, but changed in various ways in the middle of the passage. The (+) and (-) signs in the "results" column indicate whether or not the changes were noticed by the subject.

Very roughly the change from a male to a female voice corresponds to a change in pitch, although along with that change would go a change in the whole quality of the voice, (what is often referred to as the "timbre"), and it is not entirely clear which of these factors is to be held primarily responsible for the subject noticing the change. The same comment can be made about the recognition of the change to a 400 c.p.s. tone. Another slightly different condition which Cherry used was to present a short signal during a silent period of the rejected message, and this too was heard.

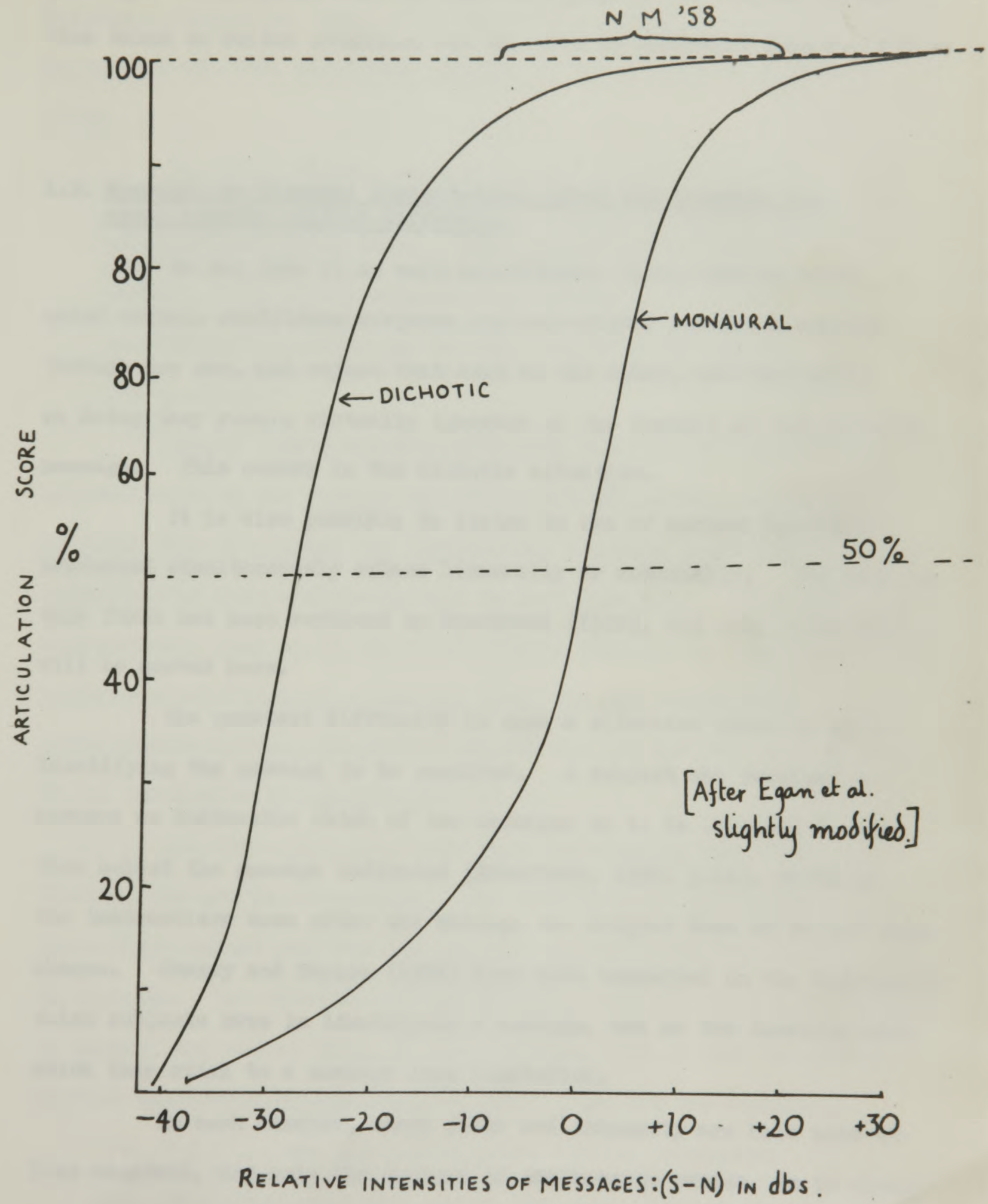
Much the most interesting condition however, is that where the central portion of the rejected message was reversed speech. If this sort of speech is listened to by itself, it sounds very unlike the speech when played forwards and yet here it is apparently being treated as it were part of the preceding message. Cherry used it because it has a statistical structure like that of speech, although it sounds different. But in a sense this is not so: for although there are conditional probabilities between signals in reversed speech, they are unknown to the subject, who in learning his language learns the sequential probabilities forwards. In language the statistical structure cannot be called similar if the signals come a - b - c - d (the normal order) and d - c - b - a: yet apparently as far as the analysing mechanisms of the brain are concerned there is sufficient similarity for the change not to be noticed. Exactly where the similarity lies will not be discussed here, but the following experiment by From (Personal Communication) will be quoted as evidence that the phenomenon occurs in other contexts as well as the dichotic listening situation. From played reversed Danish to his subjects, but told them that it was English or Swedish, distorted by radio jamming, and asked the subjects to tell him as much as they could of the content of the message. His subjects produced not merely words, but in some cases several sentences of the language which was suggested to them, so that it appears that given the right sort of "set" reversed speech does have considerable similarity to the general class of signals which are described as language; at least sufficient similarity for a subject to know that he is listening to a language and not just to a

train of sounds. Persumably many phonetics are not greatly altered although their order is. In this case the mechanism which blocks the sensory input in selective listening treats reversed speech as if it were ordinary speech.

The experiments of Cherry (1953), Moray (1959), and Miss Taylor (1958, 1959 a & b), and those reported in this thesis are the only ones so far about the perception of the content of the rejected message, but there is a paper by Egan, Carterette, & Thwing (1954), which is relevant. These workers did not use a shadowing technique, but measured the articulation score of subjects listening to more than one message under dichotic and monaural conditions. Their subjects listened to a short phrase in the presence of noise and in the presence of a competing message. Egan et al. found a very great improvement over the monaural condition in the articulation score when the messages were presented dichotically. In the monaural condition, with the two messages of equal intensity and presented simultaneously, the articulation score was only just over 50%; that is, the subjects were responding randomly to signals from both messages when the only difference between them was the meaning of the words. In the dichotic situation on the other hand, the subjects made an articulation score of nearly 100% on the accepted message. Their results are shown in Fig. (I) which is copied, with slight modifications, from their paper.

It might be asked, in view of the high articulation score which the subjects in Egan et al.'s experiment achieved, whether shadowing plays an important, or indeed any, role in fixing the attention on a particular message; but it must be remembered that there is no report in their paper of what was heard of the rejected

FIGURE I



[After Egan et al. slightly modified.]

message - merely that the articulation score for the accepted message was high. This point will be taken up again in the chapter on the time taken to switch attention and the role of shadowing (see P. 140).

1.B. Monaural or binaural presentation, pitch and intensity the same, message content different.

We may take it as well established, then, that at least under certain conditions subjects can selectively receive a message through one ear, and reject that sent to the other, and that while so doing they remain virtually ignorant of the content of the rejected message. This occurs in the dichotic situation.

It is also possible to listen to one of several messages presented simultaneously either binaurally or monaurally. The work in this field has been reviewed by Broadbent (1958), and only a few facts will be quoted here.

The greatest difficulty in such a situation seems to be in identifying the message to be received. A subject who receives in advance an indication which of two messages is to be listened to can then select the message indicated (Broadbent, 1958, p.12), while if the instructions come after the message the subject does no better than chance. Cherry and Taylor (1954) have also commented on the difficulty which subjects have in identifying a message, and on the tenacity with which they stick to a message once identified.

In such studies, where pitch and intensity are held more or less constant, and only the content of the message varies, it is clear that the statisrical structure of the messages, the learnt transition

probabilities between words, must play a very important part in helping a subject to "hang on to" whichever message he selects. As Egan et al. (op. cit.) say, apropos of the masking of speech by noise,

> "A speech signal, whether it be a single word or a meaningful sentence, can be considered as made up of a series of events, suitably chosen, having certain conditional probabilities among them. These probabilities have relatively high values as compared with the conditional probabilities of the corresponding events of a random series. Furthermore, when speech is masked by noise the conditional probabilities between events in the speech series and the events in the noise series are relatively low in value."

Cherry (1953) has also discussed the role of transitional probabilities in the recognition of one out of several messages. He found that by playing two simultaneous messages repeatedly to his subjects they were eventually able to sort them out. If however the messages were made up of trains of clichés this was no longer possible: within a cliché identification was good, but the transitional probabilities between successive clichés was too low for the continuity of the message to be recognised.

The above evidence, both from the dichotic and binaural studies, can now be summarised. For both sorts of situations a subject can select one from two or more messages when they differ only in content. The advantage of the dichotic over the binaural condition is marked, and can be taken to be a limiting case of the benefit of spatial separation of messages, of which Broadbent has remarked,

> " . . . . the conclusion about spatial separation seems to be that it is more helpful the more nearly the situation approaches that of the listener ignoring one channel and responding to another." (Broadbent, 1958, p.25.)

That the advantages are not due merely to the reduction of peripheral masking is shown by the experiments on clichés, and also by the experiment of Moray & Taylor (1958) which is described later (see p. 61 below) on the shadowing of statistical approximations to English. Broadbent (op.cit.) has commented,

> " The listener is apparently making use of the transitional probabilities between words and phrases, a factor which is clearly not sensory." (Broadbent, 1958, p.14).

1.C. Dichotic presentation, pitch of messages the same, intensity and message content different

Having established the fact that in the dichotic situation it is possible to reject one message and accept another of equal intensity to the opposite ear, let us now consider how efficiently the mechanism can perform this task when the rejected message has some characteristic which might lead us to expect that it would cause the subject to switch attention.

The most obvious condition to examine is when the relative intensities of the two messages varies so that either the accepted or the rejected message is the louder of the two. The following experiment, which the writer has reported elsewhere (Moray, 1958), was designed.

EXPERIMENT (2)

Method.

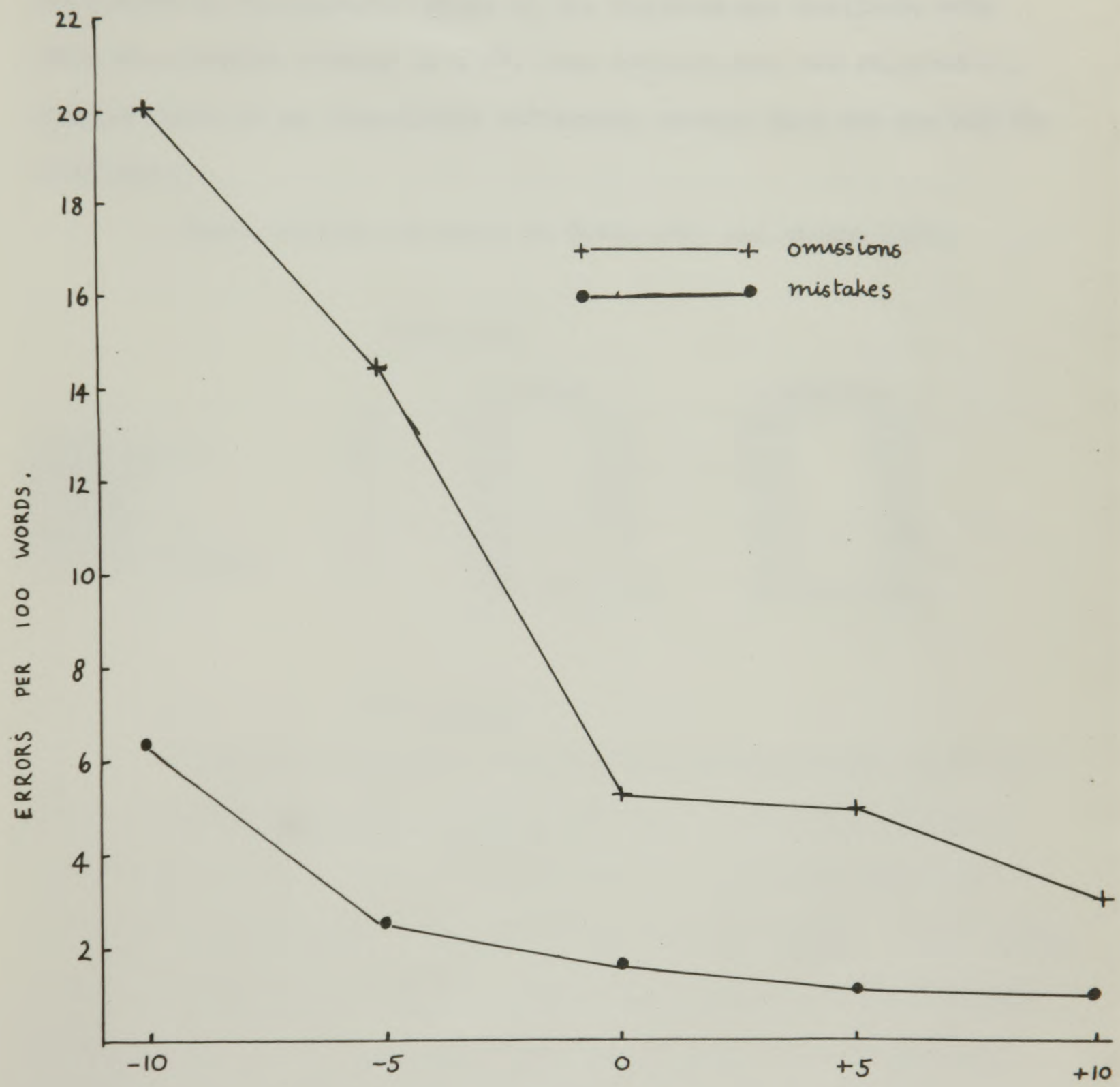
A Brennell Mark IV tape recorder was used, fitted for stereophonic recording, but modified to give two independent outputs.

The subjects received prose passages dichotically under five conditions. The passages were prose from a light novel, and were all spoken by a single male voice. The conditions were such that the intensity of the accepted message with respect to the rejected message was -10, -5, 0, +5, or +10 db. In the "0" db condition (i.e. the two messages were equally loud), each was at approximately 60 db above threshold. The subjects were all well-practised through having taken part on earlier experiments on speech shadowing. Subjects seem to have a tendency to be "right-eared" or "left-eared" in shadowing experiments, and in the present study only the "ear of choice" was used for the accepted message. The subjects' responses were tape recorded and later analysed for omissions and mistakes. There were 14 subjects, students and research workers, ages approximately 18 to 28 years.

Results.

Cherry reported (personal communication) that the relative intensity of the messages in dichotic shadowing is not critical in deciding whether a subject shall be able to shadow one of them, and the present experiment bears this out. It might be expected that making the shadowed message more intense than the rejected one would improve performance, but this is not the case. The limits of the efficiency of the response are virtually reached when the two messages are equally intense, although it does seem to be much easier for the subject subjectively when the shadowed message is more intense. If we take the difference between the mean number of omissions per hundred words when the two messages are equally intense and when the shadowed message is

FIGURE II


22
20
18
16
14
12
10
8
6
4
2
ERRORS PER 100 WORDS.
omissions
mistakes
-10
-5
0
+5
+10
INTENSITY of SHADOWED MESSAGE WITH RESPECT to
REJECTED MESSAGE: (dbs.)

10 db. more intense than the other, and submit this difference to a t - test, we find that the difference is only just significant at the 0.05 level of confidence; while if the mistakes are analysed, even when the shadowed message is 5 db. less intense than the rejected message there is no significant difference between this and the +10 db. condition.

These results are shown in Table (IV) and Figure (II).

TABLE (IV)

		Mistakes		Omissions	
	db	Mean	S.D.	Mean	S.D.
Intensity of	-10	6.2	1.0	20.0	10.5
shadowed	- 5	2.6	2.0	14.1	8.1
message	0	1.8	1.3	5.1	3.8
relative to	+ 5	1.2	1.8	4.7	6.6
rejected message	+10	1.0	1.1	3.0	3.5
		per 100 words		per 100 words	

Discussion.

Throughout the range there are more omissions than mistakes, a finding which agrees with other recent work in this field (Moray & Taylor, 1958). This point will be discussed at greater length in the theoretical section of this chapter (see p. 74 below). With regard to the small improvement with the increasing intensity of the accepted message after the "0" db point, there are two possible explanations. Schubert & Parker (1953) found that if a message was being switched between the ears, it helped the subjects to have noise in the otherwise silent gaps of the "non-message" ear. They suggested that this was because the noise helped the subjects not merely to listen to one signal, but actually gave them an added cue for listening "away from" the other.

If this is so, it is not so surprising that the limits of efficiency are reached when the intensities of the messages are not greatly different. On the other hand, it might be simpler to say that the reason that performance does not improve beyond the "0" db point is merely that it is already so good there that there is little room for further improvement. The reason that increasing the loudness of the rejected message has so little effect is probably explained by the fact that there is very little binaural interaction of messages. This point will appear again in considering a paper by Egan et al. (see below, p. 30). In general, the only interference to be expected in a dichotic situation is that due to direct peripheral masking due to the spread of sound through the head, by bone conduction.

Only the "ear of choice" was used in this experiment because it was desired to study the most efficient form of the subjects' response. Observations from other experimentsand practice sessions suggest thatthe only difference to be expected had the other ear been used would have been to have a higher initial error score, but that this would soon have disappeared with practice.

This experiment was initially done to see whether the subject would switch to the competing message when it became very loud, and this did not happen. Nor were there words imported from the rejected message in shadowing even under the least favorable conditions, as could be discovered by analysing a tape recording which was kept of their responses. The subjects were not asked how much they could report from the rejected message at each intensity, because it was assumed that the recording of their responses would give an estimate of how much

they were picking up, and also such a question makes a very great difference to the 'set' of subjects during subsequent experiments. However as measured by their overt responses, the block seems to be very efficient in the face of changes in intensity.

The difference between omissions and mistakes is now a well established finding, and Poulton (1956) gives reasons for thinking that mistakes are related to peripheral masking, and omissions to central factors, an interpretation which fits the data very well as we shall see later in the chapter, where the difference will be related to the mechanism which is responsible for keeping the subjects' attention on a given speech message in unfavourable conditions.

Once again the present experiment has a close connection with those of Egan, Carterette and Thwing (1954), who used not shadowing but an articulation score. They explored a wide range of intensities and compared the dichotic and monaural conditions. A graphical representation of their resulsts has already been given in Figure (I). It will be seen that over the range covered by the writer's shadowing experiment (marked "NM'58" in the figure), the drop in performance is of the same order, whereas the drop in the monaural situation as the disparity increases is very great. At the 50% level of the articulation score the accepted message in the dichotic situation can be 32 db. quieter than would be the case in the monaural situation. As the authors suggest, the great advantage of the dichotic condition arises from the fact that there is very little binaural masking. Although there is ample evidence for anatomical connexions between the auditory pathways of the two ears, and also evidence of interaction, (see Rosensweig & Sutton, 1958, for example), there is very little masking. Quoting from their

paper we may say:

> "When the sound pressure level of the interfering signal is 70 db., and both signals are delivered to the same ear, the threshold of perceptibility is about 55 db. SPL. When the interfering signal is delivered to the opposite ear, the threshold of perceptibility is about 23 db. SPL. Thus, by delivering the two signals to opposite ears instead of the same ear, the speech signal to be received can be reduced in intensity by 32 db. and still be just understood."

As they point out, the figure of 32 db. is about the intensity a signal at one ear must have to stimulate the opposite ear by bone conduction. So any interference that is found is probably due to simple peripheral masking by sounds which have spread in this way. A difference of intensity alone in a dichotic situation is a very ineffective way of trying to break down a subject's attention.

It will be noticed that in experiment 2, if this is the case, there must have been about 20 - 30 db. of peripheral masking at the "accepted" ear. That would give a signal/noise ratio of +30 db. in favour of the accepted message, and referring to Egan et al.'s graph, we see that at that relative intensity there should be a negligible error score, which agrees well with the writer's experiment. It may indeed be surprising that the writer obtained a mean error score of as much as 7% but of this less than 1/3 is due to mistakes (i.e. effects of peripheral masking, see above, p. 29), and the meaning of the omissions will be discussed later: at this stage it will merely be suggested that the omissions are probably a function of the shadowing situation, and are related to the repetition of the heard message.

Now on the whole these results are in marked contrast to monaural and binaural studies with noise masking of speech or several simultaneous messages. The typical finding in such cases

is that of, e.g., Webster and Thompson (1953, 1954) that the louder of two messages is more likely to be heard correctly. This is a reasonable expectation on the basis of simple peripheral masking, and such peripheral masking is known to be present in the auditory nerve response (Galambos & Davis, 1944). Tolhurst and Peters (1956), found that in a passive listening situation where the subject heard two simultaneous messages but was not "set" to respond to either selectively, the louder of the two tended to have a higher reception score in either binaural or dichotic conditions, and more so in noise than in quiet; although since they were using signals about 95 db. SPL above threshold, there would certainly have been spread from one ear to the other which may have introduced artifacts in the dichotic case. Such results are, however, what one might expect, but there are some interesting conceptions to common sense predictions.

The first is another experiment reported by Egan, Carterette, & Thwing (op. cit.). Their interest was caught by the marked change in slope of the graph for the monaural condition where the messages were of equal intensity, and upon closer inspection the rather remarkable fact emerged that there was a region where the accepted message was a little quieter than the rejected message, but performance was actually better than in the equal intensity condition. This was in the region where the relative intensity of the accepted message was about -8 db. Where the disparity was greater the articulation score fell rapidly, but at this point there was a definite significant improvement of about 8% over the equal-intensity condition. The authors commented,

> "When the two simultaneous messages are of equal intensity and of the same quality, cue conditions for identification of the appropriate signal are minimal. When the intensity of the message to be received is decreased below that of the interfering message a distinctive cue is provided. This cue partially compensates for the increased masking resulting from the decrease in intensity, and the articulation score drops less rapidly than if the interference were mere noise."

That is, the fact that there is a difference of any sort, even one which a priori might be thought to be unfavourable, aids recognition.

Another paradoxical result is reported by Jeffress, Blodgett, Sandell, and Wood (1956), in a review of binaural masking. If a pure tone is just masked by noise in a monaural situation, and noise is then added to the opposite ear, the tone reappears. If now the tone is also added to the opposite ear, it disappears again. Again the actual disparity between inputs, rather than its kind, seems to be what is important, and we shall return to these results when the time comes to consider the theoretical implications of the facts about selection in hearing which are presented here.

1.D. Dichotic presentation, message content, pitch, and intensity the same, timing of messages different

In his 1953 paper Cherry included an experiment on the relative timing of messages in a dichotic shadowing situation. The subject shadowed the message to the selected ear, while to the other ear was played the same message but delayed by several seconds. The time between the two was reduced until the subject realised that the two messages were the same. Although the report of the experiment is rather lacking in detail, Cherry gives the time

interval at which this occurred as being between 2 and 6 seconds, a surprisingly long time. During this time (whose mean value of about 4 secs we shall use in discussion), the subjects heard the message and then repeated what they had heard. In these experiments the lag between hearing and response is very short, certainly not more than a word if the subjects produce a "running" response and do not break up their performance trying to listen to groups of words and then repeat them. The response time is not sufficient to fill up the gap when it is of the order of 4 seconds (see below, p. 37) and it seems more likely that this time interval represents the time during which the trace of a signal remains in the immediate memory store after a single presentation, without rehearsal or deliberate attempts to memorise on the part of the subject.

In view of the negligible amount of material which was recalled in Experiment (1), it becomes important to examine the time relations when the rejected message is leading. The following experiment was performed, both to investigate this and to repeat Cherry's observation.

EXPERIMENT (3)

The effect of time interval on the recognition of the identity of dichotic messages

Method

16 Subjects, students and research workers, were used. Some were experienced in two-channel listening experiments, but all were naive with respect to the particular sort of experiment being done. Several short (approx. 100 words) passages of prose were recorded from a

travel book, using a single male speaker, talking in a monotone and without punctuation. This was played through two Brennel Mark IV tape recorders in cascade. That is, the tape passed the playing heads of the first tape-recorder, travelled directly to the next tape recorder, passed its playing heads, and thence to the take-up spool. The output from one tape recorder was fed to one ear of the subject, and the output from the other tape-recorder to the other ear. By sliding the tape recorders nearer together or further apart the relative time delay between the messages could be varied. A descending method of limits was used. The tape recorders were separated by a distance equivalent to 4 seconds delay, and the first passage played. The "rejected" message was faded in gradually after the subject had begun to shadow the accepted message, so that the sudden onset of a signal would not cause the subject to stop shadowing, and switch his attention. If the subject did not recognise the two messages as being identical, then the distance between the recorders was reduced to a distance equivalent to 3 seconds, and another passage played. This was continued until either the subject recognised that the messages were identical or the two tape recorders were in contact, at which point the delay was 1.25 seconds. After each presentation the subject was asked for his introspections: he was told to shadow the message that was presented to one ear, and that the experimenter was going to introduce various distortions in the signals, and that he was to remark on anything about the situation which struck him, loudness, difficulty in doing the task, and so on. Great care was taken to avoid giving any suggestion that he was to pay attention to

the "rejected" ear, and he was told in fact that this was being used to try to distract him from the proper task. No suggestion was made that the content of the message was to be taken particular note of. The advantage of this procedure was that if his attention was caught by the identity of the messages, it is certain that it was not an artifact due to his trying to listen to the two messages at the same time: a disadvantage is that if it should not occur to the subject that he is expected to remark on such features as the identity of the messages, he might seem to only recognise this at a negligible time interval. In practice this disadvantage was not serious, as there was always a very sharp transition from the point at which the subject did not recognise the identity to the next passage when they did, and they were certain when asked that there was a sharp break at this point. Owing to the apparatus used the maximum delay between messages that could be used was 4 seconds, which is the mean value which Cherry found for the recognition of identity when the accepted message was leading.

Results

The results are presented in Table (V)

TABLE (V)

Rejected Message Leading in Time:

Time Discrepancy (seconds)	Number of Subjects who first recognised the identity of the messages at this interval
4	0
3	0
2	3
1.25	3
less than 1.25	2
	n = 8

"Less than 1.25" means that these two subject had still not realised that the messages were identical at the shortest time interval which it was possible to get.

Accepted Message Leading in Time:

Time Discrepancy	Number of subjects who first recognised the identity of the message at this interval
4	8
	n = 8

That is, when the accepted message leads in time, all subjects recognised the identity of the messages when there was a 4 second delay between the messages.

Discussion

The finding in the case of the accepted-message-leading condition agrees well with Cherry's original observations, indicating perhaps that for the particular subjects and recording used in this experiment the mean time for recognition of identity would be if anything rather that just described, and has obtained substantially the same results, namely that with the accepted message leading recognition of the identity of the messages is possible over a period of several seconds (up to about 6 - 8 seconds), and that with the rejected message leading recognition occurs up to about 1½ seconds.

It might be that the large difference between the leading and lagging conditions is due to the time taken to repeat the message in shadowing. That is, there is basically no difference between the two situations, and if the subjects could keep their attention on the message indicated without having to shadow, the selective listening would break down with a time difference of only 1½ seconds in both cases. However, since it takes, say 4 seconds to listen and repeat a bit of the message when the subject is shadowing the leading

message, he is speaking the earlier part when it also arrives in the rejected message. This explanation maintains that the apparent difference in the two conditions is really an artifact of the time taken to repeat the heard message, that is, of the ear-voice span. If this explanation of the discrepancy is correct, then we should find that if we measure how far behind the message the subject repeats it aloud it will be of the order of 4 or more seconds. A priori this seems unlikely, since this corresponds to more than eight words on the average, which would bring the subject perilously close to what is the immediate memory span even under optimum conditions, but nontheless the following experiment was carried out.

EXPERIMENT (4)

Estimate of the ear-voice span in dichotic shadowing

Method

Two Brennell Mark IV tape recorders were used, modified to give independent outputs, so that both tracks could be played at once. The tape recorders were placed in cascade, as in the last experiment. Two passages of prose were recorded, one on each track, and presented to the subject dichotically. He shadowed that presented to his right ear, and his response was picked up by a microphone and recorded by the other recorder. The passage he shadowed was on the top track of the tape, and the rejected message on the bottom track. The top track of the second recorder was switched off, and its bottom track was switched to "record". Thus the subject's response replaced the rejected message as the tape passed through the second recorder.

The tape was then played back by the experimenter, and the time between the occurrence of the same word in the top and bottom tracks measured for randomly selected words. Six subjects were used, male and female, undergraduates and research workers aged 18 to 28.

Results

The results are shown in Table VI.

TABLE VI

Ear-voice span in dichotic shadowing

Subject	Mean span in seconds	standard error
G.F.	1.15	0.11
A.G.	0.95	0.05
G.R.	0.75	0.11
R.W.	1.35	0.09
C.B.	1.45	0.12
V.S.	0.85	0.09
pooled for all subjects	1.05	0.03

Discussion

It will be clear from the above results that although these were not the same subjects who actually took part in the lead-lag experiment, nonetheless we may be sure that the difference cannot be due simply to the time taken to repeat the message in a shadowing situation. To suggest this would be to assume that the subjects in Experiment 3 were drawn from an extremely abnormal part of the population, and there was nothing in their behaviour during shadowing to suggest this. We can be sure from the above experiment that the difference between leading and lagging shadowing is a genuine one, not an artifact of the ear-voice span.

1.E. Binaural or monaural presentation, two messages the same, timing different

From, (Personal Communication), presented the same message binaurally but with a time delay to his subjects. The messages were sentences, not passages of prose. The subjects reported the sentences accurately and then added that the message had been repeated. No comment will be made here on this result, beyond pointing out that this sort of overlapping message does not cause interference with the reception of the part which is overlapped in the way which Broadbent found where the overlapping messages were different, (Broadbent, 1952). This might be due to the fact that although the end of the first message was overlapped by the beginning of the second in From's experiment, nonetheless there was a clear beginning (at the very beginning of the first message) and a clear end (at the very end of the second message), and enough would be heard during the interfering part of the message for the subject to know that the two messages were the same. This explanation would not work for the situation where the time discrepancy was very short, so that much more overlapped than was clear at the ends. The point will be taken up again in the theoretical section.

This discussion of timing provides a bridge for the discussion to pass to the second question that was raised at the beginning of this chapter:-

2. Under what conditions is it impossible for a subject to listen selectively to one of two or more messages?

2.A Message content, intensity, and pitch the same, timing different

In the previous section we saw that if the two messages in a dichotic shadowing situation are the same but with a time interval between them, they can be held separate only when that interval exceeds certain values. Roughly speaking the breakdown of selective listening occurs when the interval falls below about 5 seconds if the leading message is the shadowed one, and about 1½ seconds when the lagging message is shadowed, and we saw that there is reason to regard this latter finding as evidence that there is no storage of incoming messages on the peripheral side of the filter, at least with regard to the verbal content of the message. From's experiment quoted above shows that while the subject can separate two messages in a similar but binaural situation in the sense of not suffering interference between them, they cannot be separated in the sense of the subject being only aware of one of them.

2B. Message content the same, binaural presentation, intensities different at each ear

This is equivalent to asking the subject to pay attention to one ear when the only difference between the messages reaching the ears is one of intensity. Under such conditions, as is well known, the subject does not hear two messages, one loud and one soft, but a single message which appears to move about inside his head as the relative intensities of the messages change. (see Stewart, 1932; Upton, 1936; Ford, 1942). A subject cannot keep the messages separate if the only difference between them is one of intensity; the situation becomes one of listening to a binaural message whose location appears to change.

This emphasises the finding mentioned about (Experiment (2)) and the work of Egan, Carterette and Thwing, (see pp. 20 et seq) that intensity is not a cue that is very useful to the subject nor a factor that makes his task much more difficult when it changes in a dichotic situation. It may be of help incidentally by helping to separate messages (see, e.g. Miss Taylor, 1960).

2.C. The same message content, binaural presentation, different frequencies to the two ears

It would be difficult to interpret the results of a dichotic shadowing experiment on this point, because of the different roles played by the different frequency components of a speech signal. If we consider the Fourier components of the wave, the greater part of the energy is carried by the low frequency components, but a great deal of the information is carried by the high frequency components which represent the consonants, the low frequencies being the vowels. Now if a subject were to shadow selectively a high-pass filtered message he might very well be able to say little about the verbal content of the rejected, low-pass filtered message; but this might be because it was anyway difficult to understand even when attended to. Egan et al. (1954) measured their subjects articulation scores using simultaneous monaural messages under different conditions of band-pass filtering. They found that if the accepted message had only frequencies above 500 cps while the rejected message was unfiltered, articulation scores were in the region of 75%. When the rejected message was the one that was filtered, and had only frequencies above 1000 cps, the articulation scores rose to more than 95%. These were the maximum changes from the

condition in which both messages were of equal intensity and neither was filtered, in which the articulation score was only about 50%. The high-pass filtering of the rejected message presumably is beneficial because of removing the masking effect of the low frequency components of speech, which is very marked, and much greater than that due to the high frequency components. The other effect (high-pass filtering of the accepted message) is probably related to the finding on intensity - that the introduction of any systematic difference between competing messages aids selection (see above, p.31). But from their results it is not clear what we might find in a dichotic situation.

The most relevant experiments to the dichotic condition are those of Taylor (1959) and Broadbent (1955).

There are two conditions which can be used to see whether a subject can select one of two dichotic messages which differ only in frequency in the sense of being able to block the other message completely and remain ignorant of its content. One is to use two speakers, say male and female, whose voices have a different fundamental pitch, and have them speak the same message simultaneously. This method has been used by Miss Taylor in investigating the effect of the relative timing of the messages, and from her work we may conclude that pitch alone cannot be used as a criterion for selection.

But while subjectively a baritone and a soprano voice differ a great deal, the frequencies represented in the Fourier analysis are not very different. The second possibility is therefore to use two messages which have been selectively filtered by band-pass filtering, and feed some frequencies to one ear and others to the other ear of a subject. This was done by Broadbent (1955). He removed a central band of

frequencies from recorded speech, and fed the remaining signal dichotically to his subjects. All the frequencies below 400 cps were sent to one ear, and all those above 2000 cps to the other. Under these conditions almost all his subjects accepted the situation as a binaural, single voice, situation, although there was "something odd" about it. Although his subjects were only listening to the message and not shadowing, it seems safe to conclude that the same result would hold for a dichotic shadowing situation as well, on analogy with the similarity between listening and shadowing found when we compared the results of Egan et al. (1954) and the writer with respect to intensity, and also because of Miss Taylor's results and the writer's on time delays. It is very unlikely that a subject would be able to remain ignorant of the content of one ear just because it differed in frequency from the accepted message.

It is worthwhile summarising the results of Broadbent's work as reported in his (1955) paper. Using 18 subjects he found the following.

15 subjects fused a metronome filtered as above.
8 " " a male voice intoning the vowel "i" (different records, therefore waves out of phase).
10 " " a male voice intoning the vowel "i" (same record so waves in phase).
none fused speech filtered thus and the low frequencies presented 0.25 seconds after the high frequencies.
" " a pure tone of 3000 c.p.s. and a pure tone of 500 c.p.s.

When the subjects were asked to say which ear was receiving the low pitched and which the high pitched frequencies in the original situation, after being told what was happening, their responses were random. When the two pure tones were used, no mistakes were made. This makes it

even more likely that selective shadowing could not be done in this situation.

This almost concludes the review of studies on selective listening which will be drawn on in an attempt to construct a model for the underlying mechanisms. But before going on to discuss the model there are one or two other experiments which are important but do not fit into the scheme given above.

Tolhurst and Peters (1956) remarked on the importance of slight timing differences in the onset of competing messages when one is to be selected for response. Likewise Broadbent found that it was more difficult for subjects to identify one of a pair of messages than to follow a message once identified. This holds true also of shadowing. Providing that the message to be shadowed begins even a short period before the message to be rejected subjects find it easy to pick up and shadow the selected message. If however subjects have to start shadowing in the middle of two passages presented dichotically they tend to oscillate between the signals for some time before one or other is finally selected. This would suggest that it is rather difficult to identify a message purely on the basis of apparent direction, or at least that when the messages are speech there is some factor which tends to offset the immediate and obvious advantage of spatial separation, of which Broadbent has said:

> "Thus the conslusion about spatial separation seems to be that it is more helpful, the more nearly the situation approaches that of the listener ignoring one channel and responding to another."
>
> (Broadbent, 1958, p.25)

Two other findings by Broadbent (1952) are of interest. He used a situation where subjects had to listen to a second question at the same time as answering an earlier one, and then also reply to the second. We may notice three results. An incorrect response caused more interference than a correct response: even a correct response caused considerable interference (which contrasts with dichotic shadowing where continuous speaking interferes very little with simultaneous listening): and if carrier phrases such as "hello" and "this is .." were omitted, performance fell.

Secondly, Broadbent (1952) has found that if in a simultaneous two-channel situation the subject is given a visual indication which voice he is to select before the voices speak this helps him. If however, the indication is only given after the messages, then it is of no help to the subject. He suggests that this is evidence for the operation of central factors over and above peripheral masking effects.

Let us tabulate the results quoted as far as is possible, by way of summary. The experimental condition is given on the left in each case, and on the right the sign (+) or (-) indicates respectively whether selective listening is possible or not.

a. Dichotic conditions

Messages of identical content, timing, frequency: intensity different (-)
" " " " " intensity: frequency " (-)
" " " frequency, intensity: content different (+)
" " " " : content different, rejected message louder (+)
" " " frequency, content, intensity: timing different
a) rejected message leading (+) (dt 1.5 secs)
b) rejected message lagging (+) (dt 5-6 secs)
" " pure tones, different frequency (-)

Except in the last case, (pure tones), a (+) indicates not merely that one message is accepted successfully and the other rejected, but that the verbal content of the rejected message remains unknown.

b. Binaural or monaural conditions

It is difficult to summarise the results because of the wide variety of tasks which have been used to assess the subjects' performances in these studies. In general reports have not been concerned with how much the subjects could say about the rejected message. The summary is perhaps best made in terms of how much interference there is between messages of different content.

Rejected message louder - progressive interference by masking except over a small (8db) range near the point of equal intensity.

Rejected message in different spatial position - progressively less interference with increasing separation of the messages, provided that the accepted message can be identified.

Rejected message of different frequency characteristics -
A. High pass filtering of rejected message results in less interference
B. High pass filtering of the accepted message results in less interference.

Same message with timing difference - Little interference: heard as "repeated".

c. Effect of response and instructions

In binaural listening answering one question interferes with the reception of another.

In dichotic shadowing repeating an earlier part of the message interferes negligibly with the reception of a later part.

Leaving out introductory phrases in binaural listening to simultaneous messages makes their reception more difficult.

Giving an indication before messages start as to which is to be received improves performance: giving them afterwards does not.

The timing of initial signals of competing messages is important. To begin shadowing in the middle of two passages of prose presented dichotically is difficult. With simultaneous binaural messages the one which starts a fraction of a second before the other tends to be the one received.

Let us now turn to an examination of the theoretical implications of this data.

We may notice first that in the selective process operating when a subject shadows one of two dichotically presented messages, the mechanism is acting like a filter not a switch. In Broadbent's model (1958), the phrase "filtering" was used in a general sense for any selection among possible inputs to the central perceptual system, and no systematic distinction was drawn between total blockade of input along a sensory pathway and a filtering of certain aspects of the signal. To a certain extent such a distinction is a matter of arbitrary choice: but on the other hand, there seems to be clearly distinct neurological processes, probably acting at very different levels of the nervous system,

by which a rational justification of the distinction can be made. This point will be made again in Chapter (VI and VII), but we may note now that Galambos (1955), and Hernandez-Peon et al. (1957), have apparently found total blockade of the input as far out in the auditory pathway as the cochlear nucleus in animals that were exposed to stimuli appropriate to other senses, and under artifical stimulation of the centrifugal pathways of the auditory system. Such a block cannot be operating in selective listening, at least in the dichotic experiments of Cherry, Miss Taylor, and the writer: for while the findings in the former experiments indicate the operation of a mechanism like a switch, those of the latter are like a filter, a very different sort of response. It is only the verbal content of the message which is lost in the dichotic shadowing experiments; what might be called the "raw data", the gross physical characteristics of the signal such as pitch, timbre, etc., are perceived. Broadbent has summed this up well as follows:

> "It is especially interesting to note that the features of the rejected voice which are observed are those which are useful in picking out relevant from irrelevant words in other experiments. Differences in voice are useful when one wants to ignore some words: equally differences in voice are noticed even when the words are ignored."
>
> (Broadbent, 1958, p.23).

This blocking of the pathways of the nervous system responsible for pattern analysis (which is another way of describing "meaning" from the point of view of the structure of the signal) is extremely efficient. But there are, as we have seen, some conditions under which it breaks down. The answer to the question "when does this happen?" is at its face value deceptively simple: "when the messages are sufficiently similar." But like most deceptively simple answers this one hides a

number of problems. In what sense must the messages be "similar"? We have seen for example that equally loud messages presented dichotically will only interfere (given that their content is different) in conditions where there is strong reason to think that peripheral masking through bone conduction of sound to the opposite ear is present. Likewise the messages can be spoken by the same voice, so that they have the same fundamental pitch, and yet the messages will not be confused if the content is different. And at the opposite extreme from dichotic conditions, where the two simultaneous messages are presented over one loud speaker, a chosen message can still be picked out and followed. The other side of the coin is that a difference in pitch alone is insufficient to separate messages of identical content, even in a dichotic situation, nor are intensity differences strong enough cues, although spatial separation plus a time difference are.

The obvious conclusion to draw is that some sort of comparison is done on the inputs in terms of several characteristics: these might be such things as amplitude, frequency, and phase; but apparently the more complex statistical properties of the message as a whole, the sequential probabilities of signals, are also utilised, and this requires a more complicated kind of analysis of the message.

Now it has long been accepted that there is some sort of correlation analysis done by the brain on the inputs from the two ears, and such a mechanism has been suggested to account for the phenomena of auditory localisation. Lately such ideas have been extended, for example by Cherry & Sayers (1956, and Jeffress et al. (1956). We might

assume for example that samples of each input were collected over a short time interval, compared, and that if the correlation were above some level the messages would be treated as one.

Cherry (1959) has described one correlation function which has marked success in predicting the results of auditory localisation studies; and in general, some scheme related to the following will probably be possible to develop.

Assume that the inputs are compared with respect to the neurological equivalents of amplitude, frequency, and phase, and let the resulting cross-correlation coefficients be called r_A, r_F, and r_π respectively. Assume that the brain operates on these values so that, $f(r_A, r_F, r_\pi) = R_x$ where R_x is the overall cross-correlation coefficient. By now adding the assumption that R_x must exceed a certain critical value for the messages to be heard as one, (call this R_c), we then have,

$$f(r_A, r_F, r_\pi) = R_x > R_c \quad = 1 \text{ binaural message}$$

$$f(r_A, r_F, r_\pi) = R_x < R_c \quad = 2 \text{ dichotic messages}$$

The assumption that it is the amplitude, the frequency, and the phase which are correlated is made purely for expository purposes. But the development of some such function would enable rather precise predictions to be made about when a binaural could become a dichotic situation, and the actual relation between the r's is accessible to experimental determination. This will be taken up again in the final chapter.

Let us now turn to the evidence for such cross-correlation. Cherry & Sayers (1956) performed a series of experiments based on the

assumption that the brain was functioning as a cross-correlator, and comparing the inputs from the two ears according to the correlation function

$$\phi_{12}(T) = \int_{-\infty}^{+\infty} f_1(t) f_2(t + T)\, dt$$

They gave a speech or pure tone signal to one ear, and the same signal at a time later to the other ear ($T = o \rightarrow \pm 5$ msec.) Sometimes the delayed signal was distorted or masked by noise. They asked the subjects simply to make judgements as to whether the signal was perceived to the right or left of the central position which it occupied when the time difference T was equal to zero. Their results include variations in judged sidedness for pure tones dependent upon the periodicity of the waves; similar results with intoned vowels and speech, but here complicated by the low energy components which carry most of the information. Their evidence strongly suggests the idea that certain qualities of the messages are being correlated, although they stress the fact that in everyday life there are more complex factors which come into play in the perception of speech, factors which give rise to 'Gestalten" and which play almost as great a part in determining perception as do the signals. Later, Cherry (1959) has developed this model using an autocorrelation function, not a Fourier analysis.

Another investigation is that of Jeffress, Blodgett, Sandall, & Wood (1956), who in reviewing the literature on the masking of tonal signals, said:

> "Many of the phenomena of masking can be explained on the basis of two models, one for monaural listening, the other for binaural listening. The monaural model is the familiar narrow bandpass filter followed by a detector sensitive to changes in output level. The binaural model

> is a series of coincidence detectors associated with a delay-network capable of matching a delay in the stimulus with a delay in the neural path."

Here the binaural model is clearly a mechanism for comparing the two inputs and a suitable network has been suggested by Jeffress (1948) for describing the process of auditory localisation. From their comprehensive review, we may note that the best condition for signal/noise discrimination is where the noise and the signal are presented to both ears but the noise is in phase at the two ears while the signal is out of phase. Another result already quoted is that if a tone just masked by a noise is presented to one ear, and the noise be now added to the opposite ear, the tone re-appears, while then adding the tone to the second ear makes it once more disappear. Taken together these two results strongly suggest that auditory perceptual mechanisms are very sensitive to slight differences in signals arriving at the two ears. Another result already mentioned is that of Egan et al. who found that for monaural reception of simultaneous speech, a slight fall in intensity of the accepted message with respect to the rejected message actually improved its reception compared with the equal intensity condition.

In short, the evidence that some sort of cross-correlation is being done is very strong; and Cherry's recent work may be taken as convincing evidence of this. This raises the question of the time over which the inputs are sampled. It has been suggested by various writers, (for example, Broadbent, 1958; Cherry, 1959; Welford, 1952;), that such time sampling occurs in the human organism. The suggestion has usually been made in the context of skilled movements and servo-control by kinaesthetic feedback, and while such studies are

rather far removed from the present work, they serve to emphasise one thing, namely that the sampling time must be very short if it is to be effective. Now we have seen above that a correlation mechanism would account for many binaural phenomena, and might be the basis on which the decision about binaural or dichotic perception works, but there is also evidence that events which take place on quite a different time scale are important. The greatest difference in timing between the ear which is found in everyday life, that which corresponds to a signal in a position directly opposite one ear of a subject, is much less than a millesecond. So we might expect that correlation could occur over a period of, say, a few milleseconds to allow an adequate safety factor, and we shall see that there is some evidence that this is so. But the duration of a spoken word may be very long indeed compared with this: indeed a polysyllabic word may require much more than a second for its recognition. An moreover the experiments on timing in dichotic listening by the writer and Miss Taylor (see pp.35 et seq.above) and Cherry (1953) show effects with a time course of several seconds, while the perception of sentences would seem to involve events and operations with sequential probabilities between words over even longer periods.

There is something present in a situation involving speech over and above the obvious Fourier structure of the sound waves carrying that speech. Of course two messages of different verbal content, although equally loud and spoken in a monotone by the same voice will not be "in phase" because the time structure of different words is different, but this is not all there is to it. If we look

at Broadbent's (1955) paper on binaural fusion, there are several illuminating points. From the summary given above (p.43) it will be seen that in the basic condition of the high frequencies being sent to one ear and the low frequencies to the other, the subjects could not say which ear was receiving which. This is most interesting, because it shows that what we would expect to be very clear cues for sidedness (namely a very large frequency difference between the two signals), seems to be overridden by what can only be described as the "verbal content" of the message being similar (in fact identical). On the other hand this similarity is not sufficient to override a time difference between the messages of 0.25 seconds to the extent of hearing them still as one message. As Broadbent says of these experiments,

> "The nature of the sounds which are or are not fused suggests that the important factor in producing fusion is the temporal relation between the arrival of stimuli at the two ears."

We should note that while the disparity in temporal events of pure tones causes them to be perceived as two distinct messages, the disparity of speech in this respect is overridden by the similarity of meaning. But as soon as we say this a vastly more complicated kind of comparison is introduced. To respond in terms of meaning is to make use of long term memories, of the learnt transition probabilities between words, and so on. Cherry and Sayers (1956) have remarked:

> "Speech is notoriously resistant to distortion; it may be filtered, infinitely clipped, submerged in noise, interrupted, and mutilated in unlimited ways, yet what remains is usually recognisable to some degree to a human listener . . . . . Regarded as a superb device for dealing with hypotheses, the brain receives signals as evidence, weighs the alternative

> hypotheses in the light of them and of its pastexperiences, and accepts one as a working solution for the moment."

We may also fruitfully quote some other papers, in which the authors speak in similar vein. The first is Cherry again, this time from his original paper on shadowing (1953), in which he drew attention to Shannon's finding that subjects respond in terms of probability rankings of words when given printed speech. Taylor (1956) has reported a similar finding using the "cloze" procedure in asking subjects to guess missing words from prose. Goldmann-Eisler has recently drawn attention to other aspects of responses to varying amount of information in response to speech. More explicitly, Egan et al. (1954) in the paper already frequently quoted, speak thus of the confusion of one message with another:

> "the differences between the masking of speech by speech and the masking of speech by noise might be summarised as follows. A speech signal, whether it be a single word or a meaningful sentence, can be considered as made up of a series of events, suitably chosen, having certain conditional probabilities among them. Those probabilities have relatively high values as compared with the conditional probabilities of the corresponding events of a random series. Furthermore, when speech is masked by noise the conditional probabilities between events in the speech series and the events in the noise series are relatively low in value. On the other hand, when the interference is another speech message, not only are the probabilities high within the series of interfering events but they are also high between the events of the signal and of the interference. For this reason an interfering speech message not only masks the speech signal (in the sense of peripheral masking), but becomes confused with it."

Finally a short quotation from Broadbent (1958, p.14), sums up the point neatly. Speaking of Cherry's (1953) paper he says,

> "The listener is apparently making use of the transition probabilities between words and phrases, a factor which is clearly not sensory."

Now if the factor is not sensory, but depends on the learnt transition probabilities between signals (both within and between words and phrases), this immediately suggests another possibility, and one which explains why a speech "message", as such, as an individually identifiable series of events, is so compelling. The suggestion is that when part of a message is perceived there is a feedback from the long term store of conditional probabilities and comparison of an earlier part of the message with the later parts of the message as they arrive. The ability of a subject to select and shadow one of two dichotic messages can now be described in terms of four interacting factors.

1. Impulses descend from the higher centres of the brain and mediate the decision to listen to one ear or the other.

2. The sensory inputs from the two ears are cross-correlated and if the value of R_x is very high then the selection introduced by (1.) is overrulled and the messages are heard as one binaural message.

3. The earlier parts of the message are used to predict the later parts of the message on the basis of long-term-store learnt transitional probabilities, and these predictions are compared with the actual signals which arrive in the later parts of the message, by a device which is error-sensitive to departures of the arriving signals from their predicted structure.

4. The predictions are compared not only with the input from the same ear but also with the input to the other ear by a process which we shall call "cross comparison".

It should be noticed that while pattern analysis in the sense of word recognition involves the use of the long-term store of conditional probabilities, as does the calculation of those probabilities, step (4.) does not require pattern analysis previous to the comparison whether with the message of the same side "self comparison" or "cross comparison" the prediction could be made in terms of, for example, the successive values of the Fourier components of the input or of the wave form of a time sample. This is important because of the role that timing plays in the breakdown of selective dichotic listening. This model will explain all the data reviewed in this chapter. It is at present admittedly a fairly loose description, lacking in detail: the threads will be drawn together at the end of this chapter in the light of the following discussion. But it should be noted that in principle it is possible to make quantitative predictions about the sorts of message which will be heard as one message and the sort that will be heard as distinct dichotic messages.

The block set up functions as a filter: the pathways to those parts of the brain concerned with pattern analysis are blocked for the "rejected" sensory input, but the "raw data", that is speech regarded merely as sounds, does reach the level of conscious perception. Now suppose that the subject has a 'set' to accept the message from one ear, and that the message received by the other ear is very different in content. Then R_x will be low, so that there will not be binaural fusion, and since the accepted message is normal speech, the "self comparison" function (which will be called R_s) will be high, while the "cross comparison" function (which will be called R_p)

will also be low. So the subject can easily follow the selected message, for there is no tendency for the messages to fuse, since R_x is low; there is no tendency for the messages to be heard as the same but repeated, since R_p is low; and since R_s is high the message being followed is easily identified, and can be "held" with no difficulty. (Since the error between prediction and the incoming signals is small there is no tendency for the mechanism to switch to the other input as being more capable of filling the predictions.) If now the two inputs begin to become more similar, R_x will rise, and there will come a point ($R_x > R_c$)where the messages will fuse and will be heard as a binaural message localised to one side. If the message contains words which are the same from time to time there will be momentary fluctuations in R_p which will allow data from the "rejected" message to reach consciousness also. If the message becomes the same but one delayed in time by a small amount, the rise in R_p will cause the "block" to break down.

While the possibility of there being a mechanism which performs "cross correlation" is an idea which has been held for some time, that of "self comparison" via the feeding back of learnt conditional probabilities as the explanation of the peculiar tenacity with which subjects can at times selectively listen with one ear is new. It has been prefigured, however, in many researches implicitly, such as those quoted above (p. 54-55 and more explicitly in Broadbent, who in describing his model for selective perception says the following:

> "Postulate C. The selection is not complete random, and the probability of a particular class of events being selected is increased by certain properties of the events and by certain states of the organism." . . . . . ."
> Postulate F. Given that two signals have been selected one after another, the conditional probability of the second given the detected occurrence of the first is stored within the nervous system in a long-term (relatively slowly decaying) store." . . . . . "
> Postulate I. . . . . (Long term storages does not effect the capacity of the channel, but rather is the means for adjusting the internal coding to the probabilities of external events; . . . . . "
> (Broadbent, 1958, p.298).

And in the information flow diagram there is a pathway by which the conditional probabilities of the long-term store can feed back and affect the selective filter. But Broadbent relates this mainly to theories of learning, such as Deutsch's (1953) and does not discuss in detail the way that it functions directly in the selective listening situation. There are three types of experiments which provide results which fit neatly into the framework of such a theory, that is, a combination of self comparison of each message with the later parts of itself (R_s) and the cross comparison of the two sets of feedback probabilities, one from each message (R_p).

Firstly, there are the experiments, already described, of Cherry (1953), Miss Taylor (1959 unpublished), and the writer (p.33 above), on the effect of altering the timing of dichotic messages whose content is the same. We are faced with this problem: the subject is unaware of the verbal content of the rejected message but then comes to realise that the messages are the same. But if he never hears the rejected message, why should his attitude to it change? How can he ever realise that the two messages are the same?

The rejected message is faded in once he has begun shadowing, and the two messages are stopped before either reaches its end, so that there is no period when he hears the rejected message by itself. The assumption that the subsequent signals are predicted on the basis of learnt conditional probabilities and these predictions are compared with the inputs from both ears explains this. There will come a point where the correlation is high with respect to both inputs, (both R_s and $R_p > R_c$) and at that point the chosen message cannot be selectively held while the subject remains ignorant of the other.

Secondly, in the same paper (1953) Cherry studies the reception of messages composed of strings of clichés. The situation was one in which simultaneous messages were presented binaurally, not dichotically, but the results support the idea of the R_s comparison. The subjects could recognise individual clichés very readily, but were not able to follow a continuous message composed of clichés. They tended to switch from one message to another at the break between the clichés. This we can interpret by saying that given the start of a cliché the rest of it is very readily predicted, and the error sensing device is able to follow the signals composing it easily: the error between prediction and the incoming signals is negligible. Between one cliché and another, however, the conditional probabilities are very low, and in fact there is very little reason why one should come rather than another, within the rather vague constraints imposed by the context of the message as a whole. There is not a high R_s to give a cue for the identification of which part of the signal

composes the next part of the message, so that selection fails, and other factors such as relative loudness, time of onset, etc., override the voluntary selection.

Thirdly, the following experiment, by the writer and Miss Taylor (Moray and Taylor, 1958), is relevant.

EXPERIMENT (5)

Method

Our method differed from Cherry's in that we used a dichotic method of presentation. Also, instead of presenting two messages composed of clichés, we presented one message which was ordinary prose, taken from a light novel, and another which was composed of statistical approximations to English. The subjects were 26 undergraduates and research workers, some of whom had had previous experience in two-channel listening, but all of whom were inexperienced in shadowing.

Eight passages of 100 words were composed by the method of Miller and Selfridge (1950): that is, people were asked to add one word to sentences of which they could see varying numbers of words previous to the one they had to add. In this way passages of 1st, 2nd, 4th, 6th, 8th, 12th, and 16th order approximations to English were made. The expression "order of approximation" is due to Shannon (1949) and a 6th order approximation for example, is one in which the subject can see the five words preceding that which he adds when the messages are being prepared. A first order approximation is obtained by picking words at random from a book, in this case a novel, so that the words have no contextual constraints but occur with approximately the

TABLE VII

	Order of approximation to English X								
	1	2	4	5	6	7	8	12	16
Mean omissions	3027	15.5	15.8	15.6	5.0	11.8	2.6	6.8	4.3
s.d. of mean	15.4	7.8	9.8	11.0	6.4	7.7	3.0	7.4	4.1
Mean mistakes	8.1	5.7	5.1	5.0	2.6	4.1	2.9	2.6	2.5
s.d. of mean	7.2	3.8	3.5	4.1	2.5	3.4	3.9	1.8	2.2

n = 26

frequency that they do in everyday use. During the experiment it became desirable to have samples of 5th and 7th order approximations, and these were prepared from the lists of Miller and Selfridge by combining their shorter passages into 100 word groups by adding suitable bridge words to join them, care being taken to preserve the statistical structure across the gap. These approximations were played to one ear of the subjects, while to their other ear was presented a passage of light prose (from the novel "Perelandra" by C.S. Lewis). All the passages were read in a monotone, and the two messages were balanced at approximately equal intensities. The lists were presented in order from the highest to the lowest order of approximation, so that any practice effect would reduce the errors in those passages we expected subjects would find it hardest to shadow. One passage of normal prose was included as the last of all to be shadowed so that any falling off in performance due to fatigue could be assessed. Any such effect if present was found to be negligible.

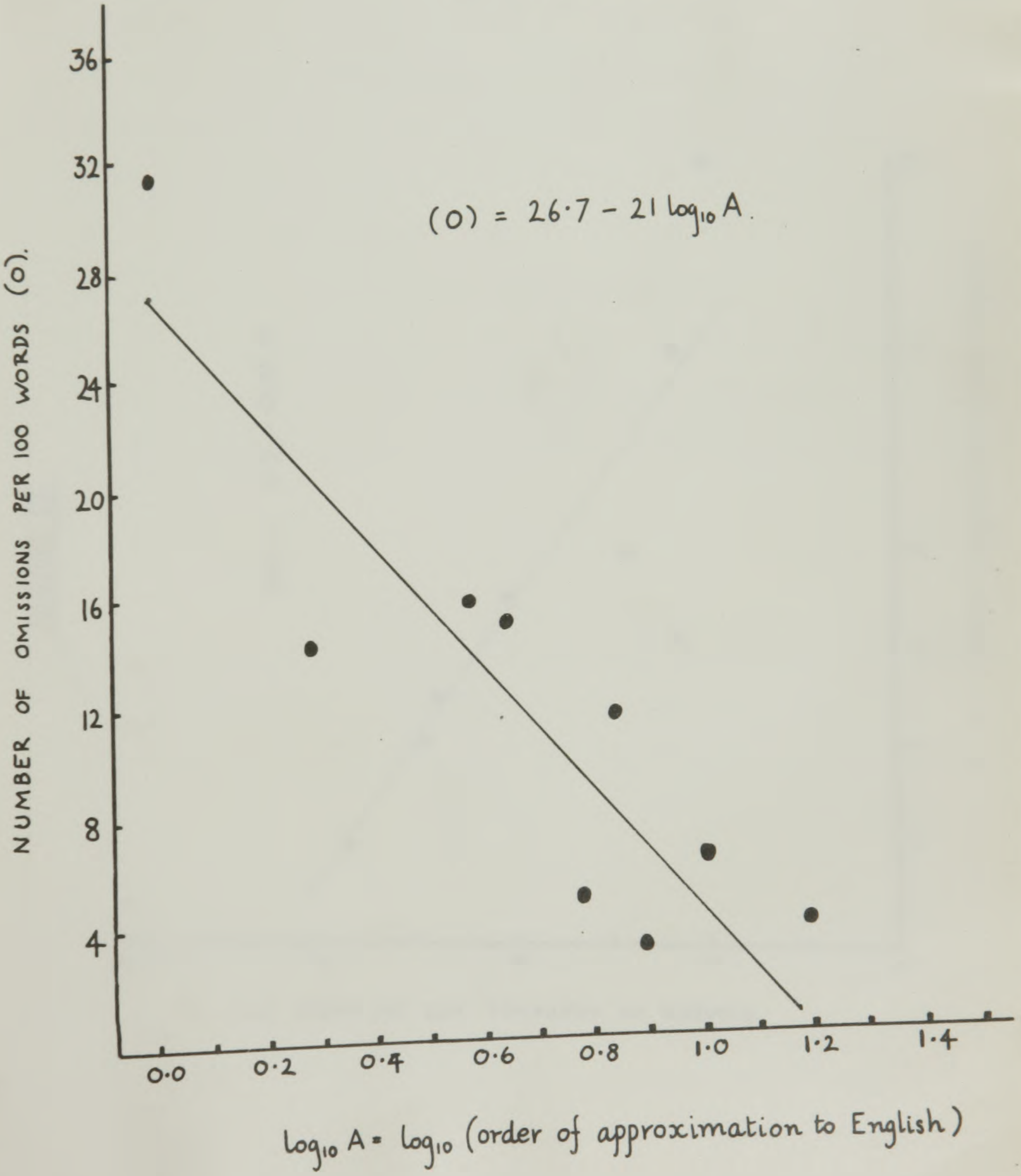
The subjects were thus required to shadow approximations to English while rejecting normal English presented to the opposite ear. The subjects responses were recorded on tape, and analysed later for omissions and mistakes. Fresh words introduced were counted as omissions, but these were so small in number that to have counted them as mistakes would have made no difference to the analysis of the results.

Results

Our results are analysed in Table (VII).

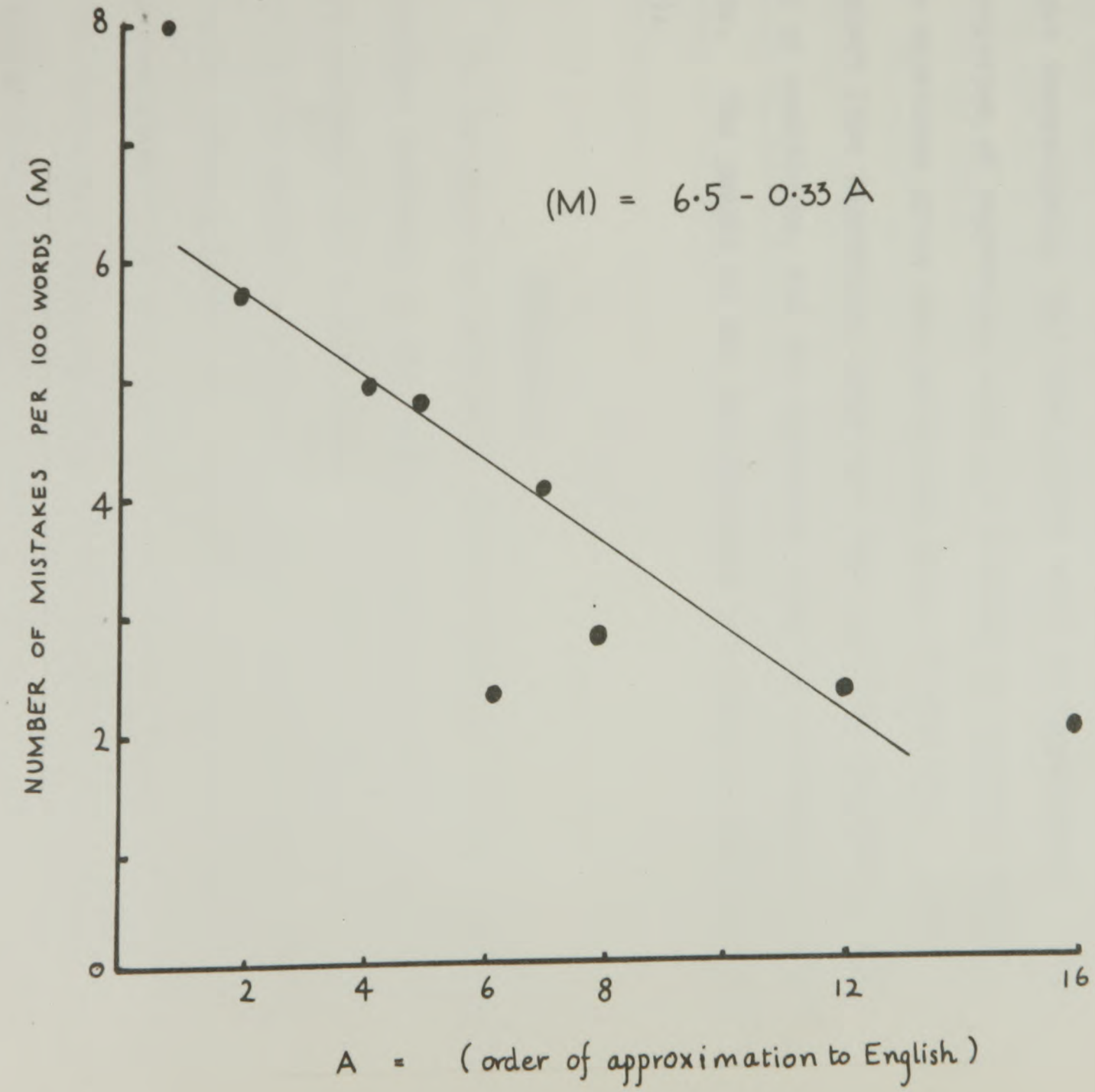
The errors were estimated by counting the number of individual words which the subjects omitted or got wrong. Curves were fitted to

FIGURE III.



$(O) = 26{\cdot}7 - 21 \log_{10} A.$

FIGURE IV


(M) = 6·5 - 0·33 A
NUMBER OF MISTAKES PER 100 WORDS (M)
8
6
4
2
0
2
4
6
8
12
16
A = (order of approximation to English)

the data, and the following equations were obtained as curves of best fit.

Omissions = 26.7 - 21 $\log_{10}$ (order of approximation.)
Mistakes = 6.5 - 0.33 (order of approximation.)

Other curves were tested to see if they would also fit the data in particular with a view to checking the mistakes equation, as we thought theoretically that both curves would be logarithmic. But the calculation of regression lines and analysis of variance showed that the equations given were definitely those of best fit. Both plots depart from regression lines less than would be expected at the 1% level of confidence, and the omissions curve is considerably better than this. The graphs of the two equations are shown in Figures (III) and (IV).

Discussion

In the paper as published, the results were related to the amount of information contained in the various orders of approximation, but a different emphasis will be made here. In the first place we may note that even in the hardest conditions of all the subjects did not switch to the normal prose passage, nor - as far as we could tell from their recorded responses - did they begin to include words from the rejected message in their shadowing responses. But the difference of structure was affecting them in some way. The difference between the relative numbers of omissions and mistakes is in line with most other work which has recently been published, although it is a little puzzling why the number of mistakes should rise at all if, as Poulton suggested, they are due chiefly to peripheral masking. It may be that their

increase at the lower orders of approximation are not in fact due to increased difficulty in reception so much as to increased difficulty in speaking, for one comment which almost all the subjects made was that at the lower orders they heard the words all right but "just couldn't get them out", and we may have scored distorted response as wrong words when they were wrong only in the sense that the subjects were having increasing difficulty speaking. But this itself raises the interesting question of the nature of this very compulsive inhibition of the motor output. Why could the subjects not speak when they knew what they wanted to say? In our paper, Miss Taylor and the writer discussed tentatively the possibility that there was some sort of "motor set" which arose in the subject. The idea was that the prepared his responses slightly in advance, thus limiting the number of words from which he was going to speak, and that when the messages were low order prose, this set was contradicted and so the motor output was suddenly inhibited. We wrote:

> "The first requirement for successful shadowing is that the material should be perceived accurately; and as Miller Heise, and Lichten (1951) have shown, the effect of context introducing redundancy in a perceptual task is considerable. It seems possible that incoming information (in the informal sense) is used to predict what words will follow, thus making the task of deception easier by narrowing the class of possible words and syntactical structures from which an identification will have to be made. It is also possible that similarly a motor set might arise, limiting the probable responses that may have to be made, and making output easier. At low ordersof approximation, where redundancy is low, this set will have to be changed more often as the context changes over smaller groups of words, and this task will presumably be performed at the expense of the motor output. It is worth noting that to randomise words not merely introduces random order but actually make the perceptual task harder than would be predicted, for randomisation may actually contradict learnt transition probabilities."

> "Why should errors and redundancy be related in this way? If, as is suggested by the work of Broadbent (1952), listening and speaking are sufficiently different for it to be necessary to switch attention to one activity at the expense of the other if an efficient response is to be made, then if the incoming message varies in some unusual way which makes it necessary for the subject to pay more attention to reception, output will suffer, and the number of omissions will rise. It may be that the redundancy of the message produced an effect analagous to persistence of vision in a cinema, in that it allows the "gaps" in reception due to switching to be filled in."

In the model put forward by Broadbent (1958) there is a pathway shown whereby the long-term store of conditional probabilities can directly influence the effector output, and the suggestion of the role of "motor set" made in the first of the above quotations could be mediated by such a mechanism. Two other findings not directly apparent from the data should also be mentioned. At the lower orders of approximation not merely were there more omissions, but they tended to come in runs: and at these orders of approximations if subjects listened to several words and then spoke them, rather than constantly repeating what they heard as they heard it, their performance deteriorated more. Several volunteered the introspection that they changed from the "listen and then speak" to the continuous form of response as the passages became more nonsensical.

It appears from the difference between the omissions and mistakes that subjects tend to make no response rather than a wrong response. This, together with the disadvantage of the "listen-and-speak" form of response, can be explained by the R_s system.

If the subject listens to several words, and then makes a response, the prediction of the next word after the group which he has stored will tend to be high, for the more words heard the more

certain, in general, what the next word will be. This is the theory behind the construction of the statistical approximations to English. Usually, when listening to normal English, this would be a good strategy to adopt, for although according to Broadbent's (1952) paper speaking the words will interfere with the reception of the next few, these have been predicted with a great deal of accuracy, and the redundancy of the signal plus this prediction - that is, the operation of the R_s mechanism - allows the "gap" to be filled (see the quotation on the previous page). But when the material is becoming more and more nonsensical, this is a disastrous strategy, for the more words the subject stores the more certain he becomes of what the next ones are going to be. But with low orders of approximation this means he is going almost always to be wrong, and he will lose the thread of the message. For if he can predict, and the prediction is confirmed by R_s, then he can both "fill in the gap" and also be sure that he is on the same message even if he misses a word. But at low orders of approximation the context changes so rapidly that it is difficult either to fill in the gaps or to pick up the thread. Now a continuous running response does not tend to build up a very definite prediction in this way - if the subject could treat the message as a train of single signals in fact he would probably do very well, for the message would for him still be redundant even at low orders. And because a running response does not leave gaps, the R_s prediction goes on steadily and the response is more efficient, although the task is hard for the subject because he is used to using R_s with messages which are highly redundant. It is better on a correlation model to leave words out than to speak wrong ones, for to speak wrong ones is equivalent to a prediction that the message is

going to follow a certain course which at low orders is precisely what it does not do; at least it does not follow the course which one would expect on the basis of learnt transition probabilities. To quote again from our paper,

> "Mistakes would alter the transition probabilities for succeeding words and therefore make errors more likely, while merely not responding at all would not have any such effect."

By not responding, that is, momentarily cancelling the processing of the message and starting again, the effect of any false predictions upon response would be nullified, otherwise they would tend to have a positive feedback effect until the response broke down: it might indeed be something of this sort which is causing the compulsive motor blocking which subjects experience in this situation. That false predictions about context do have a deleterious effect upon reception of speech has been shown by Bruce (1958), who asked subjects to repeat messages heard in the presence of noise. By suggesting false or true contexts to them he could produce a very marked influence upon their scores. Similar suggestions have been made in the context of skills and fatigue by Welford, (1953), where he speaks of cumulative disruption of performance.

This account has not followed the discussion which we undertook in the original paper about the different amounts of information in the various samples of English approximations, but it is clear that if prediction in terms of the learnt sequential probabilities is being utilised by the subject to identify the message that he is following, changes in information will affect the predictions by altering the probabilities. It should be noted that although at the low orders of

approximation the learnt sequential probabilities will be contradicted by the message, nonetheless because of the way in which the passages are constructed, the sequential probabilities of successive words in the approximations will tend to be higher than the probabilities of a word from the approximation followed by a word from the prose passage on the other ear, so that the R_s system will help the subject to follow the selected message: although the rejected message would be easier to follow, the mechanism can prevent the messages from becoming confused.

The effect of timing on selective listening falls into three parts. Initially a single message is heard, which as the time difference increases becomes altered in its apparent localisation. At a slightly longer time interval, the voice "tears apart" (Cherry & Taylor, 1954), and is heard as two voices saying the same thing. And when the time disparity becomes very great, it is possible to reject one message altogether as the correlation between received and subsequent signals on opposite ears becomes very low. [redacted].

What inferences can be drawn from these times? In terms of the correlation model suggested above, they may be interpreted thus.

Between 0 and 20 msecs., the cross-corelation of the raw data input from the two ears (whether in terms of the wave envelope or a Fourier analysis) is high ($R_x > R_c$), so there is fusion, and the messages are heard as one, whose localisation changes. When the speech signals are out of step by 20 msecs., R_x falls to less than R_c and

the messages are heard as dichotic. This is an important result, because if the interpretation is correct, we have here a baseline for analysing the nature of the function

$$f(r_A, r_F, r_\pi) = R_x$$

and the relation between its components. By examining the way in which speech waves differ when out of step by 20 msecs. with the overall intensity and pitch held constant, we have a way of arriving at the value of R_c, and hence an avenue of research for determining under what conditions messages will be heard as one or as two messages, leading to quantitative, rather accurate predictions comparable with those of Cherry on localisation. It may, of course, be found that the 20 msecs. depends to some extent on the speech rate, although since it is so short a period compared with the length of speech signals as a whole that it is unlikely that it will alter much. If the variation is important, this would mean including a fourth parameter in the function described above.

When the disparity is greater than 20 msecs., R_x for the inputs is low, but R_s for each message is high, and so is R_p, so that the filter is overridden even if the subjecttries to listen to only one ear, and two coherent, dichotic, voices are heard, saying the same thing.

When the time discrepancy is greater than 1½ secs. the situation becomes complex. R_x - the cross-correlation of the sensory input is now very low, in fact virtually zero for a 20 msec. sample, so that there is no tendency for the messages to fuse. R_s for either ear is still high, so that for each ear the message is coherent. Up

to this point both messages are feeding back R_s predictions to their own inputs, and also to each others. But at about this point R_p falls to a value where if one message can be selected for a short period the filter can operate, block the pathways to the pattern analysis and long term store mechanisms for the rejected message, and therefore cut its signals off from the level at which they are consciously perceived. At the same time R_s for the accepted message remains high and allows the subject to shadow selectively one of the messages. If the rejected message leads in time, there is no longer a cross correlation of its conditional predictions (R_p) because the pathways to the long term store, necessary for the calculation of these conditional probabilities, are now blocked. So if the rejected message leads the messages can be held separate. If on the other hand the accepted message leads, its conditional probability predictions are fed back and compared with the input of the opposite ear: since the pathways to the long term store are open for the accepted message, the R_p comparison can still be done. The value of R_p does not fall to less than R_c until a time lag (at least for a speech rate of about 135 words per minute) of about 5 - 6 secs. is present. This time we may take to be that during which a memory trace endures and can be utilised by the subject, in the short term memory, after a single presentation, without rehearsal, and with no particular set to remember. It agrees well with Broadbent's estimate of the time course of short term memory decay (Broadbent, 1958, p. 298, Postulate H) but the relation between these two estimates will have to be discussed further (see Chapter V). Here memory trace is used in the sense of activity initiated by a specific signal remaining in the

whole circuit of perception-long-term store-prediction-comparison mechanism.

This model, in terms of R_x (cross-correlation of sensory input with a short sampling time), R_s (self comparison via prediction on the basis of learnt transition probabilities between earlier and later parts of the message), and R_p (cross comparison of the R_s predictions of the message of each ear with subsequent parts of the message of the opposite ear), will also explain many of the other results reviewed in this chapter.

1. It accounts for the importance of carrier phrases in introducing messages (Poulton, 1953; see p.45 above). These now provide the initial data for the three correlation calculations, so that the subject is already listening to the correct message when the information bearing part of the message arrives. Without carrier phrases, part of the message is utilised in identifying which sounds form the sequence which is to be followed, and until the R_s calculations have achieved this, the subject is uncertain what to listen to, and so some of the message will tend to be confused and lost.

2. It accounts in a similar way for the importance of timing in the onset of messages, (Egan et al. (1955)). If the selected message begins a fraction of a second before the other both its direction will have been identified, and also the initial R_s predictions will have got under way so that subsequent signals belonging to the same series will have a better chance of being recognised. Getting the R_s predictions started is probably part of the mechanism of what is called "set" in this situation.

3. The relative effect of instructions before and after the presentation of a message also fits here: by saying which call-sign is to be received, the subject is "pre-set" to receive messages which correlate with the characteristics of the voice using the call-sign, so that R_s and R_p can be set up and the selected message followed, the other being rejected. If instructions are only given afterwards, both messages must be received, with resulting interference.

4. The three-way comparison model also explains the findings about omissions and mistakes in shadowing experiments, as described above (p.63) in the experiment using statistical approximations to English. In general the account for any messages goes as follows. Suppose that in shadowing a subject arrives at a point where he falters. To make a wrong guess at the word is to feed wrong predictions to the R_s mechanism. These predictions will then be falsified by the next signals which arrive, and the subject will rapidly lose track of the message. To omit a word or words merely weakens the prediction for a few moments, but does not result in its being falsified by incoming signals, so that an observer trying to predict the later events of a Markov series such as speech on the basis of earlier members of the series would be adopting a better strategy to omit guesses when in doubt than to guess wrong. This seems to be what the brain does.

5. Cherry's findings about the reception of clichés in a double channel situation have been described in terms of the model already (see p.60 , above.)

6. The model offers an account of the somewhat complex interaction of pitch, intensity, localisation, timing, and context in dichotic selective listening, by suggesting a way of measuring how "similar" messages must be to be heard as a single binaural message. If correlation is being carried out with respect to a number of characteristics then a low r for some of them might be offset by a high r for others (for example, pitch and context in Broadbent, 1955).

7. Egan et al (1955) found that for messages of equal intensity and pitch presented simultaneously in a monaural situation the articulation score was about 50%, i.e. the subjects were shifting randomly from one message to the other. The messages they were using were lists of words, not running speech, and therefore the R_s correlation could not help to identify subsequent signals from a message on the basis of earlier ones, and since there were no consistent differences between the messages of any other kind, it became a matter of chance which of two simultaneous signals were heard.

8. Jeffress et al (1956), reporting on masking effects in general, described the effect of adding noise to the opposite ear to that which was receiving noise and a just-masked signal (see P.32 above). In terms of a correlation of inputs their findings become intelligible. If both noise and signal are present to both ears in phase, correlation is perfect (R_x) and if the signal is just below threshold it will not be heard. Nor will it be heard if the situation is monaural. If the signal is present to only one ear, however, but the noise to both, correlation is no longer perfect, and as Jeffress et al, said, a <u>difference</u> in the stimuli (but not the signal itself), will be heard. The subjects do not pick the signal out of the noise

and hear it as such, but hear a difference of some kind.

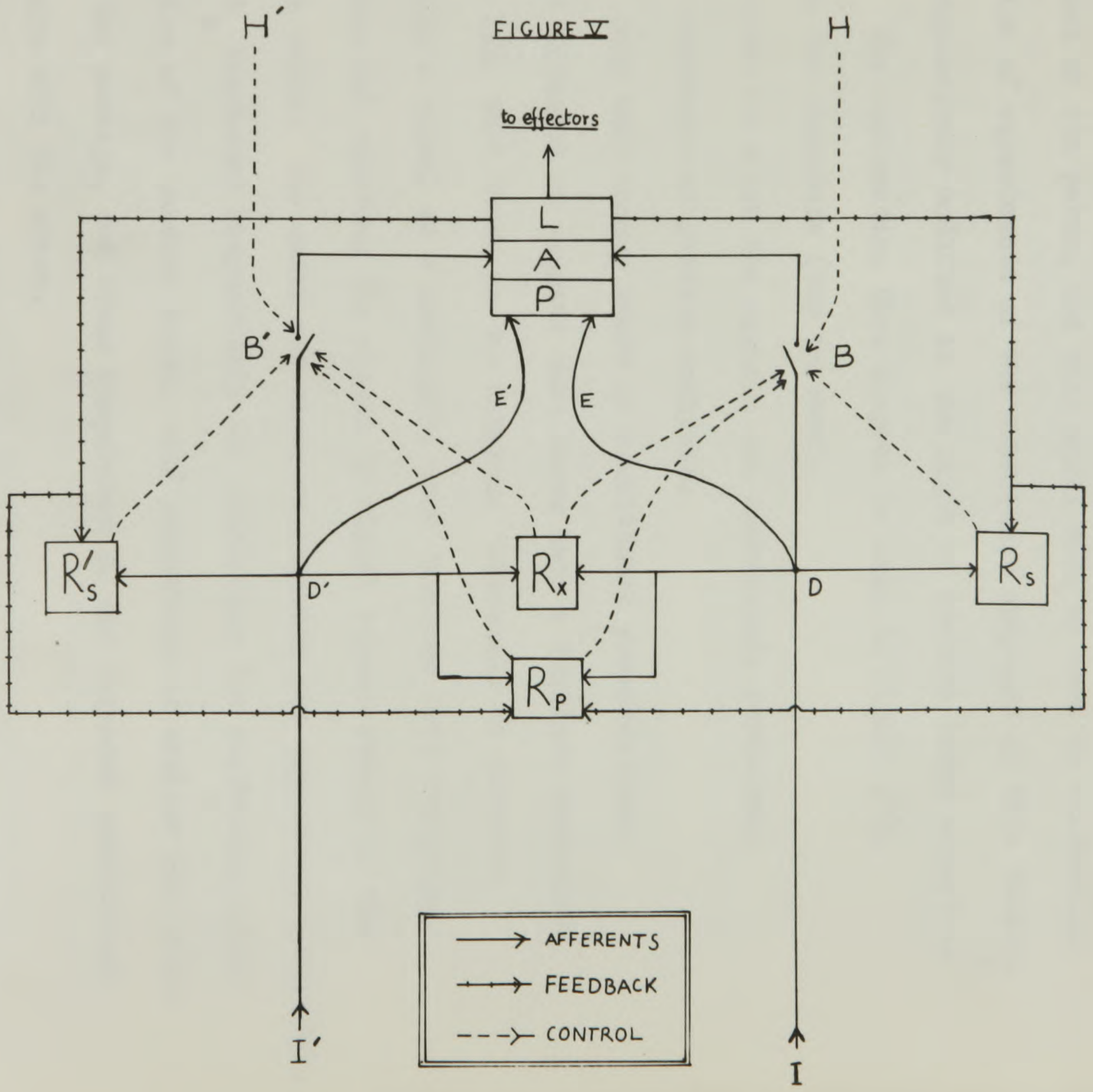
9. The last result which we shall consider in the light of the proposed model is the finding of Egan et al. (see above, p. 32), on the effect of slight intensity differences in monaural simultaneous speech conditions, of which they said,

> "If the message to be received is more intense than the message to be ignored, the expected improvement in efficiency is obtained. If the message to be received is somewhat less intense than the interfering one, the cue value of the intensity difference offsets the increased masking of the less intense by the more intense message."

The explanation of this is similar to the previous one (8 above).

At present the model is admittedly in a rather vague and qualitative form. The writer agrees with Broadbent (1959, p. 301 et seq.) about the relative merits of qualitative and quantitative models, but the presentation of the former is of course no excuse for vagueness. It does appear, at least, that a system which performed the operations suggested would have many of the properties which would be needed for selecting and following messages arriving over several channels, (which might or might not be different spatially), if those messages were of the general class called Markov chains, such as speech is generally held to be. Also, despite its vagueness at present, the postulate that correlation is being done on the basis of a small number of the characteristics of the messages, taken with the findings about the importance of timing in particular, means the model is vulnerable to experimental attack by altering the correlation of the various parameters which might be expected to be used in such comparisons, and therefore

FIGURE V


H′
H
to effectors
L
A
P
B′
B
E′
E
R'_S
D′
R_x
D
R_S
R_P
AFFERENTS
FEEDBACK
CONTROL
I′
I

is not entirely sterile.

With these considerations in mind, the information-flow diagram of the model will now be presented; together with a detailed description of its parts, and this model will be used in discussing the results of experiments of the subsequent chapters of this thesis, being progressively modified in the light of results there reported.

The information flow diagram is seen in Figure (V).

I, I' are the receptors (the two ears).

P isthe level at which the signals are consciously perceived.

A is the mechanism of pattern analysis.

L is the long term memory store of conditional probabilities.

(It is not intended to suggest that these have a distinct anatomical relation like that shown in the diagram: obviously to perceive consciously a signal as a meaningful word involves both analysing its pattern and relating the signal to signal traces stored in the long term store: the units are shown as separate for expository purposes).

R_x, R_s, R_p represent respectively the mechanisms for performing cross correlation of the sensory input, self comparison of earlier and later parts of the message, and cross comparison of the fed-back predictions of one side with the other.

H, H' represent the pathways by which impulses from higher centres in the brain effect selection.

B, B' are the mechanisms for blocking the pathways to the pattern analysis mechanisms.

Signals entering through I can reach P by two routes. The first, which is not shut off if the subject is listening to the input from the other side, is by way of the path labled IDEP. Signals passing

through this system are heard as sounds, not as words. If the signals are to be interpreted as words, they must passthrough the alternative pathway IDBA, so that they are analysed in A and related to the traces in L. If the subject were (by means of the pathways H, H') to listen to the input from I' and reject I, then B is open and B' closed, so that signals from I cannot pass through B to A, and so the meaning of the message is lost, although the sounds are still heard merely as sounds.

If the correlation between the sensory inputs is high as measured by R_x, then the effect of H, H' is overridden by impulses transmitted by the pathways R_xB, R_xB', and both the switches B and B' are closed, the messages then being heard binaurally. R_p plays a similar role, based on the correlation between earlier and later parts of the two messages, while R_sB, $R_s'B'$ keep the subject shadowing the message on one ear as described above in the earlier parts of this chapter. Whether the subject hears a single binaural message, two dichotic messages, or a single dichotic message selectively is therefore determined by the interaction on each side of the system of HB, R_xB, R_sB, and R_pB.

The general outline of the model is similar to that proposed by Broadbent (1958). But several points of difference should be noted. In the first place, the model is conceived as being sharply limited: it is intended to be applied only to the auditory system, where there are two clearly defined sensory input pathways to the central nervous system, where there is little summation, and where - unlike vision - a subject can voluntarily elect to receive signals from one set of receptors rather than the other. The writer does not

think that it represents a general plan for selective perception as a whole. Secondly, it will be seen that the whole system of correlators amounts to a suggestion for the structure of that part of Broadbent's model which in his book (1958) is labled simply "selective filter". Thirdly, and most important, it will be seen that there is no provision in the model for a short term memory store between the receptors and the filter mechanism, such as is described in Broadbent's model. In the present model the short term store is conceived of as involving the circuit which is indicated as PLR_pP, (or Effectors -I-A-P-Effectors if oral rehearsal is used), or simply the decay of the trace in R_s and R_p if there is no rehearsal. Broadbent needs the short term store previous to the filter to account for some of his results in the field of simultaneous listening to two lists of random numbers, and this point will be discussed further below; it is probably the major difference between the present model and Broadbent's. (Once more it is emphasised that the present model is only meant to apply to the auditory system: there may be a short term store in the other sensory modalities such as Broadbent suggests. It should be noted that "correlation" is used in a general sense, not in the strict mathematical way that e.g. Cherry uses it.)

The form of the model here presented is based only on the work so far reviewed and described. That is, studies in which the characteristics of the speech messages were those of ordinary descriptive prose. We shall now turn to certain more specialised responses of the selective listening system - the icing, as it were, on the cake of two-channel listening.

C H A P T E R IV

Complex Variables in Selective Listening

> "A may be our sweetheart, Z may be some condition of our soul's salvation. Under these circumstances if we succeed in attending to Z at all it is always with expenditure of effort."
>
> William James, Principles of Psychology.

The quotation heading this chapter is only one of a very large group which lay emphasis on the importance of "affectively toned" stimuli as determiners of attention. A quotation equally fitting, although rather less colourful, might have been taken from Titchener, who described in his list of stimuli which catch the attention a group which have,

> "certain qualitative characteristics . . . . . they are intimate, worrying, wicked things."
>
> (Titchener, 1903).

Moreover such stimuli can clearly alter behaviour in many ways. In everyday life the lover hears the wind whisper the name of his beloved where the objective observer notices only the rustling of leaves in the breeze; while in the more esoteric field of psychological theory the whole conceptual framework of perceptual defence turns on the acknowledgement of this fact.

However while there is ample anecdotal evidence of the importance of this class of stimuli, there is a remarkable dearth of experimental data - at least with regard to the attention catching properties of the stimuli.

Experimentally the most relevant work seems to be that on subliminal perception, where such workers as Dixon (1956), and Lazarus and McCleary (1951), have produced a large volume of data, albeit whose significance is still in dispute. But the studies on subliminal perception are not really comparable to the present study, in so far as in the work being reported here the "rejected" stimuli are presented at an intensity which normally would be well above the perceptual threshold if the situation were a monaural or binaural one; it is only the selective decision of the subject to disregard the channel through which they are arriving that leads to the stimuli going unperceived.

A typical example of the anecdotal evidence referred to above is one of the features of the "cocktail party problem" of selective listening under noisy conditions. It is widely held that a person will hear his own name even if it is spoken rather quietly in the midst of that surrounding bedlam which is so common a feature of such situations. But there is no built-in "control" for such belief. That would necessitate a comparative study of the number of times that the name was heard and the number of times that it was missed during a party, and on this we have no data.

Having found, as has been reported in the previous chapters that the attentional block in selective dichotic shadowing is so efficient, it seemed of particular interest to use this situation to confirm the suggestions about affective stimuli.

The following experiment was devised.

EXPERIMENT (6)

Method

A Brennell Mark IV sterophonic tape recorder, modified to give two independent outputs through attenuators to headphones was used to present passages of prose to the subjects. The headphones were wired for dichotic presentation. Matching for loudness was approximate, and was done by asking the subjects to match subjectively two standard passages. Matching was to within ± 1 db of the average speech level, an accuracy which as we have seen does not significantly alter the shadowing performance; (above, p. 27). The subjects were undergraduates and research workers of both sexes. Before the experiment each subject was given four passages of prose to shadow for practice. 12 subjects were used.

Subjects were required to shadow ten short passages of light fiction. They were told that their responses would be recorded, and that the object of the experiment was for them to try to score as few errors as possible. In some of the passages instructions were interpolated, but except in the last two cases subjects were not warned of these. On some occasions the instructions were prefixed by the subject's own name, which was specially recorded for each subject. The order of presentation is given in Table IX

Table IX

Commands and Order of Presentation

Passage	Command at start of message	Instructions within passage
I	Listen to your right ear	All right you may stop now
II	" " " " "	No instructions

III	Listen to your right ear	John Smith you may stop now
IV	" " " " "	No instructions
V	" " " " "	Change over to your other ear
VI	" " " " "	No instructions
VII	" " " " "	John Smith change over to your other ear
VIII	Listen to your right ear; you will receive instructions to change ears	Change over to your other ear
IX	Listen to your right ear	No instructions
X	Listen to your right ear; you will receive instructions to change ears	John Smith change over to your other ear.

The "no instructions" passages were interpolated into the table at random, but of the others, in each case the instructions without names were presented before the corresponding instructions with names, as it was thought thatit was less likely that the subject would develop a set for that particular instruction at its second presentation if they were given that way round. Most of the subjects in fact ignored even those instructions which were presented in the ear which they were shadowing, and reported that they thought that these were just attempts by the experimenter to distract them. The way in which the instructions were interpolated in the messages is shown in "Passage VII."

"Passage VII."

Pre-passage command "Listen to your right ear"

Right ear: The flashes were incessant. In between them when
Left ear : He was beginning to feel the first symptoms of

he looked in any direction except that of the clouds, he saw
exhaustion and was beginning to become confused completely

a completely changed world. It was like being at the centre of
by the riot of colours in the atmosphere. How long this state

a rainbow or in a bath of multicoloured steam. The water which
of affairs lasted he could not say, but the next thing he re-

now filled the air was changing sea and sky into a bedlam of
members John Smith change over to this ear noticing with any

flaming writhing transparencies. He was dazzled and now for the
accuracy was that the swell was decreasing. He got the impress-

first time a little frightened. In the flashes he saw as
ion of being near the end of a long range of water mountains

before only the endless sea and the still green column at
and looking down into lower country; for a long time he never

the John Smith change over to your other ear end of the
reached this lower country; what had seemed by comparison

world. No land anywhere, not the suggestion of a shore from
with the seas he had met with on his first arrival to be calm

one horizon to the other. The thunder was earsplitting and
water always turned out when he rushed down into them to be

it was difficult to get enough air.
only slightly smaller waves.

The passages were presented in a steady monotone, and checked with a valve voltmeter to ensure that the level of intensity when the name was spoken was not significantly greater than the general level of the message. The subjects' responses were recorded and later analysed.

The results are given in Table X.

Table X

Relative frequencies of hearing of affective and non-affective instructions when presented in the rejected message

	Affective (instructions preceded by subject's name)	Non-affective (instructions not so preceded)
Number of times instructions were presented	39	36
Number of times instructions were heard	20	4

Pooled data for 12 subjects

Results and Discussion

Since there were twelve subjects, and the data were pooled, there should have been 36 sets of instructions presented which were preceded by the subjects' names in the rejected message. The discrepancy is due to three subjects who heard the instructions and actually changed over, so that the second set of instructions in that passage were presented to what then became the rejected message. These three cases all occurred in passage X. The mean number of instructions heard in the two conditions per subject was calculated and the difference submitted to a t - test. The difference between the affective and non-affective situations is highly significant, since $t = 3.05$, giving a level of confidence better than the 1% level, at which $t = 2.81$.

We may conclude that the affective value of a stimulus, as exemplified by a person's own name, is extremely important in determining perception in a selective listening situation.

On only four out of the twenty occasions on which the affective instructions were heard did the subject actually change to the other message, and in one of these the subject then spontaneously returned to the initial message without noticing that he had done so. On the other occasions the subjects reported hearing the instructions during the pause between passages or at the end of the experiment.

The relative frequencies of hearing following different sorts of instructions are given in Table XI.

Table XI

Relative frequencies of hearing affective instructions

Instructions	Total No. of times heard
John Smith you may stop now	4/12
" " change over to this ear	4/12
" " " " " " " (after being told of instructions: Passage X)	11/15
	Pooled data 12 subjects

While the difference between the last class and either of the first two is not significant at the 5% level of confidence by X^2 the difference does suggest that the effect of instructions might be to alter the set of the subject in such a way as to increase the chance of material from the "rejected" message being perceived. A further experiment was devised to test this idea.

EXPERIMENT (7)

Method

Two groups of subjects were required to shadow one of two simultaneous dichotic messages. The same apparatus was used as in the previous experiment. In some of the messages digits were interpolated. One group of subjects was told that at the end of the experiment they would be asked questions about the content of the shadowed message. The other group was told that they were to remember all the numbers that they possibly could.

The general scheme of the experiment is shown in Table IV. The continuous lines represent prose. It will be noted that owing to a deficiency in experimental design, certain numbers were presented in

both the shadowed and the rejected messages. These were not included in the subjects' scores for either the shadowed or the rejected messages when the scores were analysed. For the first group (general set-to-remember) there were also several passages included in which questions were asked as to whether the subjects had heard certain words in the passage, and some passages with numbers in which the questions were not about the numbers but about the verbal content of the message, so that a specific set-for-numbers was unlikely to develop. The second group received only the passages with numbers, and their instructions were as follows; "You will hear two messages, one to each ear, and you will be told which you are to listen to and repeat. Included in each passage will be some numbers. At the end of each passage you will be asked to repeat any numbers that you have heard. If the passage continues after you have heard the numbers you must continue to shadow, but try to remember the numbers. The mistakes you make in repetition count against you, the numbers you repeat count for you. So repeat all the numbers that you possibly can. Your object is to remember all the numbers you can."

The design of the passages is shown in Table XII and the results in Table XIII.

Table XII

Passage I:	R. Ear	3 9 7 1
	L. Ear	6 1 2 5
Passage III:	R. Ear	5 1 6 8
	L. Ear	4 6 3 5

Passage V:	R. Ear	7182
	L. Ear	6423
Passage VII:	R. Ear	5138
	L. Ear	
Passage VIII:	R. Ear	
	L. Ear	2983
Passage IX:	R. Ear	5498
	L. Ear	2681

Table XIII

Numbers recalled under conditions of general and specific set from the rejected message

	General Set			Specific Set		
	total	mean	s.e.	total	mean	s.e.
Number spoken (S)	8/240	0.63	0.19	10	0.83	0.25
Number recalled (R)	15/240	1.25	0.40	18	1.5	0.45

Discussion

It was expected that the difference in the instructions in the two conditions of general and specific set would result in more numbers being reported in the latter condition, since one of the effects of thus "setting" a subject is to make the relevant stimuli "important" for him. The difference of the mean number of digits actually spoken by the subjects while shadowing, (S), in the two conditions was submitted to a t - test, and similarly the difference

between the numbers recalled (R). In neither of the cases did the difference approach the 5% level of confidence. But both for (S) and for (R) the mean number reported from specific set condition was slightly higher than under the condition of general set, and the possibility must remain open that if the experiment had been continued long enough with more subjects, the results might have become significant. The present finding does not rule out the possibility that an alteration in voluntary set might make material sufficiently "important" to break down the attentional barrier set up in selective dichotic shadowing, but it does indicate that to alter the subject's attitude to the stimulus to the desired degree is much harder than might have been thought, in the light of the ease with which instructions can affect performance in many laboratory experiments. It is also relevant here with Broadbent's contention that the "filter" in selective listening can be set to select certain classes of words (Broadbent, 1908, p. 54).

It is worth remarking on two points which do not appear in the summarised data of Tables XII and XIII. Firstly, even in passage VII, where there were no digits in the passage which the subject was shadowing, only once did a subject report numbers. This subject was given a specific set, and also was a psychologist engaged in research and notorious for his tendency to set up hypotheses about the purpose of experiments when being a subject, with resulting vagaries in performance. In the present case he announced after passage III that it had occurred to him that there might be numbers on the "wrong" ear, and that henceforth he was going to try to listen to both ears. In passage VII he reported all four digits; but his shadowing of the message he was meant to listen to was grossly inaccurate, suggesting a switch of

attention rather than a genuine breakdown of the block by incoming material.

The second point that is worthy of remark, concerns passage IX. Here the digits are staggered, so that the two messages end

5 4 9 8

2 6 8 1

In the light of Broadbent's (1954) work on the presentation of simultaneous digits, it is rather surprising that the subjects did not pick up any of the numbers from the rejected ear, for the rate of speech was fairly slow, about 1 digit per second on each ear. Admittedly according to Broadbent an even slower rate is needed for the correct perception of pairs of <u>simultaneous</u> digits. But it is surprising that apparently none of the rejected message digits were reported. In this connexion the following experiment is also relevant.

EXPERIMENT (8)

Method

A Brenell tape recorder was used as above to present dichotic and also binaural stimuli to subjects. The general design of the experiment was a modified form of that used by Broadbent in the study cited above. The subjects heard groups of 6 digits which were presented either dichotically, three to each ear; or binaurally. In the dichotic condition the numbers could arrive either in simultaneous pairs, or staggered. By passing the dichotic stimuli through a mixing box before they were presented to the subjects the binaural condition was obtained in which, therefore, the stimuli were either simultaneous

pairs, or successive. The speed of presentation used in the dichotic condition, was 2 digits/ear/second. When mixed and presented binaurally, this became 4 digits/second. The subjects were required to listen to each group of six digits, and immediately recall as many as they could. Ten groups of six digits were presented in each run, with a ten second pause for the subjects reports between each. The subjects were given one practice run of ten groups before starting, and then received the binaural lists. The order of presentation for the dichotic lists was varied so that half the subjects received the staggered before the simultaneous conditions, and vice versa. Subjects were asked (in the dichotic series), to recall numbers ear by ear (successive), that is L L L R R R; or alternately L R L R L R.

The type of stimulus, rate of presentation, subjects performance, and statistics are summarised in Table XIV.

Table XIV

	Presentation	Recall	Rate	Mean errors per 10 6-digit lists	S.E.	Condition
binaural	successive	free	4/ear/sec	3.0	0.7	A
	simultaneous	free	4/ear/sec	9.9	1.3	B
	staggered	successive	2/ear/sec	11.3	2.0	C
dichotic	simultaneous	successive	2/ear/sec	10.0	1.7	D
	staggered	alternate	2/ear/sec	13.5	1.9	E
	simultaneous	alternate	2/ear/sec	19.9	2.1	F

16 subjects were used.

Discussion

From the results it will be seen that while subjects are unable to repeat the digits in their correct form when they arrive in simultaneous dichotic pairs and recall is alternate, (which is the same result that Broadbent found), they can do this quite well if the signals are staggered when they arrive. (Compare conditions E and F: the difference is significant at better than the 1% level, while the difference between conditions C and E is not significant at the 10% level; both by *t*-test).

In other contexts these results are of considerable theoretical importance: they have been discussed by the writer elsewhere, (Moray, 1960),and will be considered in Chapter V. Here we need only to look at one feature of the results. In condition E, the signals arrived staggered at the two ears at a rate of 2/ear/second; and yet the subject was quite able to switch from one message to the other and accept them at that rate. Now in Experiment (7), (above, pp 87 et seq), in passage IX, the digits at the end of the passages were staggered in this way, and arrived at approximately half the rate, and yet none of those from the rejected message were heard. Moreover when the subjects were specifically asked to say whether they had heard any of the "rejected" digits, they uniformly claimed that they had not - not merely that they could not remember them, but that they had not heard them at all.

The experiment just described (Experiment (8)), shows that they could have had ample time to switch between the messages. And

since the numbers were staggered there were in fact moments of silence in which they would not have missed any of the numbers on the shadowed ear. (Compare Passage IX with passage III in this respect). But they did not switch, nor apparently did they hear any of the "rejected" digits.

Bearing in mind that in Experiment (I) (pp. 9 et seq.) the only people who heard any of the words of the rejected message remarked that they came during a gap, it seems that one of two interpretations of this is possible. Either in Experiment (I) the gap was particularly long, or the effect of set in Experiment (7) was to reinforce the "locking onto" the accepted message so that now even gaps of this magnitude were not enough to make the subject pick up material from the wrong message. We saw in the previous chapter (pp. 65 et seq, e.g.) that there were reasons for thinking that the sequential probabilities of the message were important in determining what the subject would do in a shadowing performance, but the sequential probabilities between random digits are nil. However in these experiments the subject is instructed to follow the message sent to one or other of his ears. We might think of this as introducing a "bias" into the mechanism - on an analogy with the effect of biassing a radio valve - and that the effect of set in an experiment such as Experiment (7) is to alter the value of the bias so that an even "stronger" competing signal is needed before it will break through. Alternatively, we might think of the effect of this "bias" as operating on a system which has a certain amount of inertia, so that even if the accepted message ceases, there will be a short time lag before the switch "swings over", and that the effect of the set increases

the inertia, so that if the subject were set to switch rapidly between channels, as in the experiment on listening to trains of 6 digits, the enertia would be lower than when he is set to listen to one channel and reject the other.

These theoretical considerations will be taken up again in the conclusion of this chapter: for now it is sufficient to draw attention to the fact that thdy indicate an inter-relation of set, signal intensity, probability relations in the signals, etc., of a considerable complexity.

One possible criticism of the experiment on set described above (Experiment (7)), is that if the critical factor at work is the "importance" of the signal to the subject, merely telling the subject to recall numbers is not a suitable means of conducting the experiment. Unlessthe sample of subjects contained an unlikely percentage of dedicated followers of Pythagoras they are hardly likely to be sufficiently stirred by the perception of numbers as to regard them as comparable in importance with their own names! With this possibility in mind, another experiment was designed, although it is worth pointing out that unless we are discussing nervous mechanisms, there is no point of critical importance which would result from a series of negative results in such experiments - most of the subjects had had names for about 20 years, and while comparable "setting" or conditioning would be hard to achieve in a short term experiment, failure to achieve it would not rule out its possibility given time enough. This experiment can thus be regarded as an attempt to gild the lily of selective listening studies, rather than make the thing grow in the first place.

EXPERIMENT (9)

Method

An attempt was made to make a neutral word "important" to the subject by pairingit with electric shock. The subject was connected to a galvanic skin response apparatus, and throughout the experiment his GSR was recorded. This was done in two different ways. Either an exosomatic source of potential was used (a 1.5 volt accumulator) and recording was by visual observation of the beam of a "moving spot" galvanometer whose reading was taken every 2 seconds: or an EEG apparatus was used, with continuous pen recording of the endosomatic skin potential.

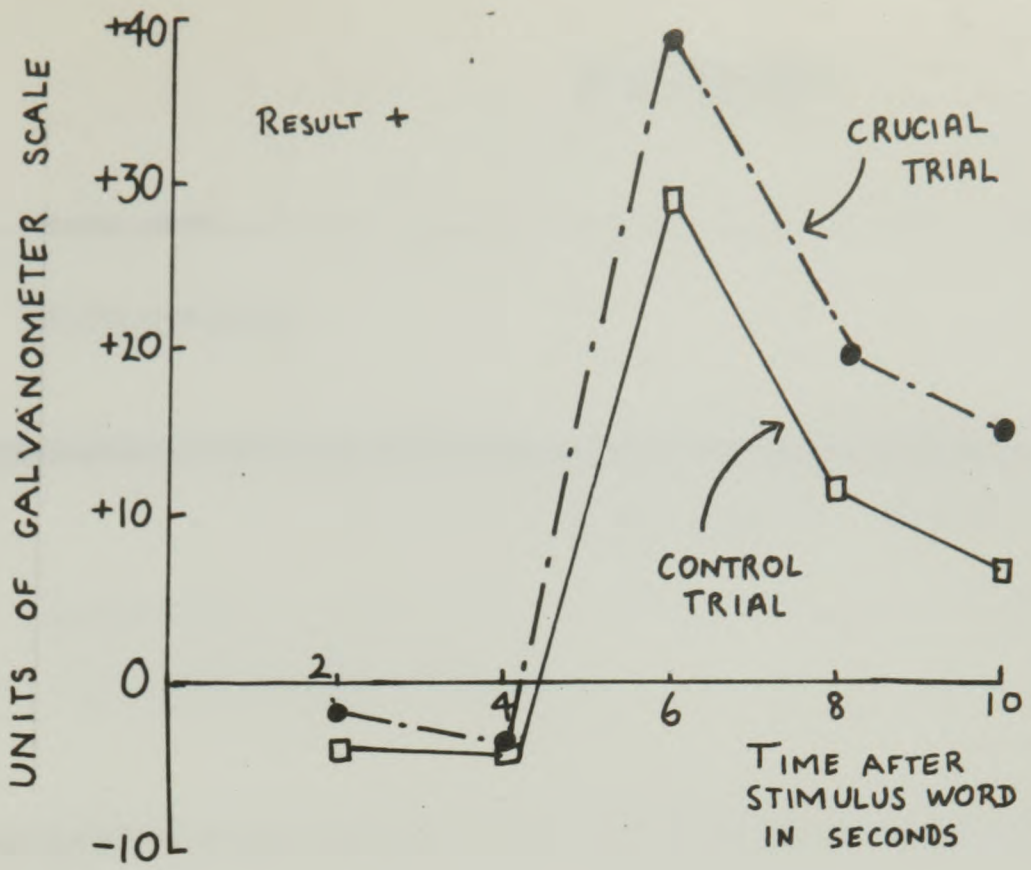
The subject first shadowed a binaural passage of prose, in which the word "COUNTRY" appeared. A note was made of the effect of this word on the GSR, and in no case did its occurrence have a noticeable effect. The subject then shadowed five prose passages, all binaurally, in each of which the word COUNTRY occurred. The stimulus messages were presented by means of a Brenell Mark IV tape recorder, and were monitored by the experimenter. When the word COUNTRY occurred in the message, the experimenter momentarily closed a morse key, and delivered a shock to the subject through the secondary of an induction coil driven from an accumulator. (The strength of the shock was previously adjusted as follows. The electrodes were placed on the subject, and a series of shocks were given to the subject. These began by being imperceptible, and the secondary coil was moved in by centimetre steps, until the subject said that he did not want the shocks

to be any stronger. At this point the secondary coil was moved in a further ½ centimetre, and this strength of shock was used throughout the experiment. It was in all cases enough to make the hand visibly twitch when it was applied.)

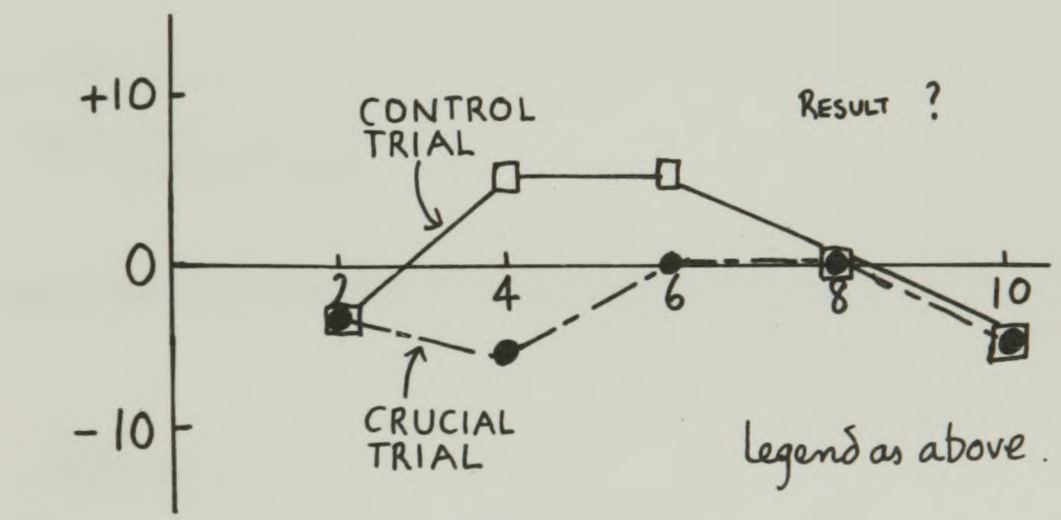
After five conditioning trials, one passage was given in which no shock was given, and the GSR response observed. It had been previously found that if subjects did not condition by this stage they were unlikely to condition even if more than double the number of trials was used. If no conditioned GSR was observed, the subject was rejected and the experiment finished. It there was a well established GSR to COUNTRY, one more conditioning trial was given to offset the extinction effect of the no-shock trial.

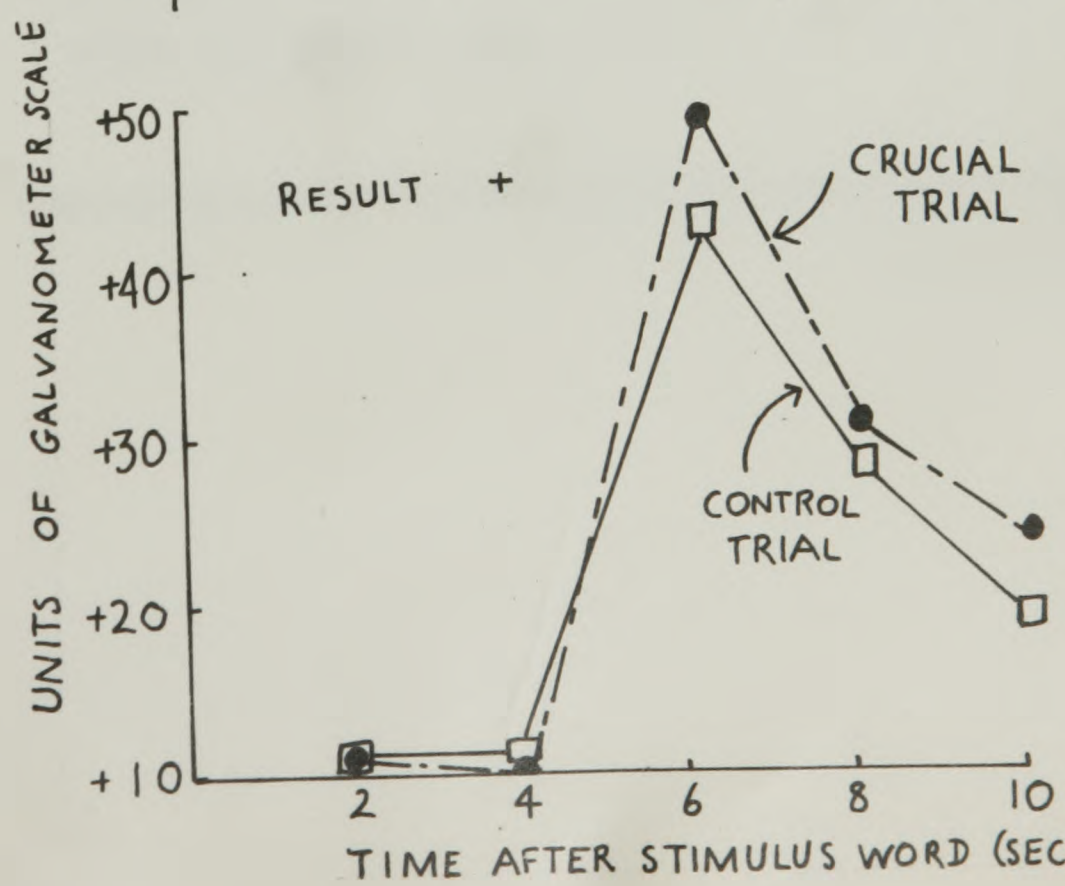
The subject was then told that in the second part of the experiment the same thing was going to be done, but that he would listen to one ear while another message was played to his other ear in an attempt to distract him. Two trials without shock were then given. On the first, the subject shadowed the message to his right ear, and the word COUNTRY did not appear in it; while it <u>was</u> present in the rejected message. The rejected message was monitored by the experimenter and a search was made for a GSR in response to COUNTRY. In the second trial, the subject shadowed the message which contained COUNTRY and a record of the GSR was similarly made.

The purpose of the second trial was to ensure that there had not been inhibition of the response due to the change in experimental conditions from binaural to dichotic shadowing. In no case was there such inhibition.



IN THE CONTROL TRIAL "COUNTRY" OCCURS IN THE SHADOWED MESSAGE





IN THE CRUCIAL TRIAL "COUNTRY" OCCURS IN THE REJECTED MESSAGE

FIGURE VI

FIGURE VII a

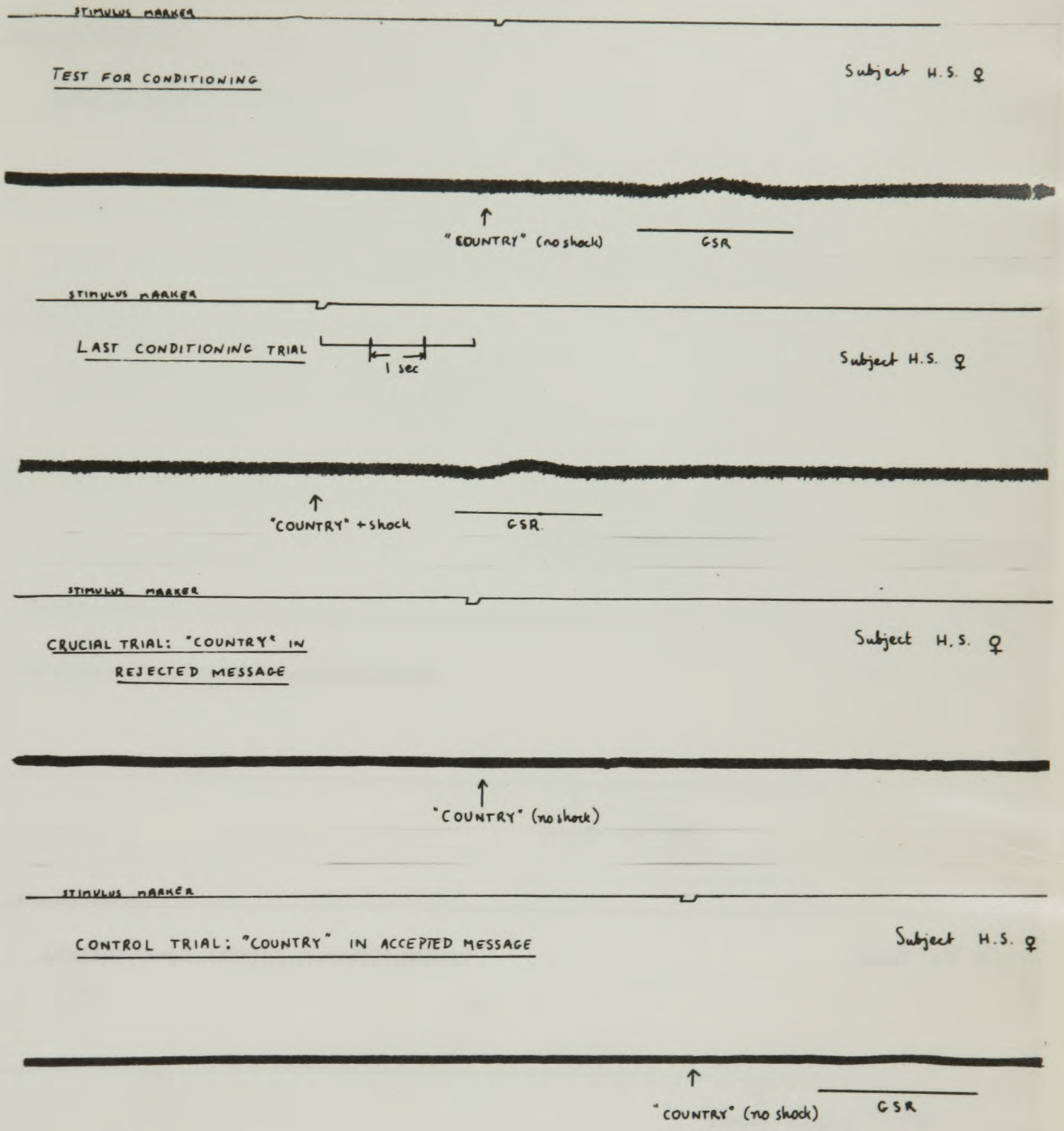
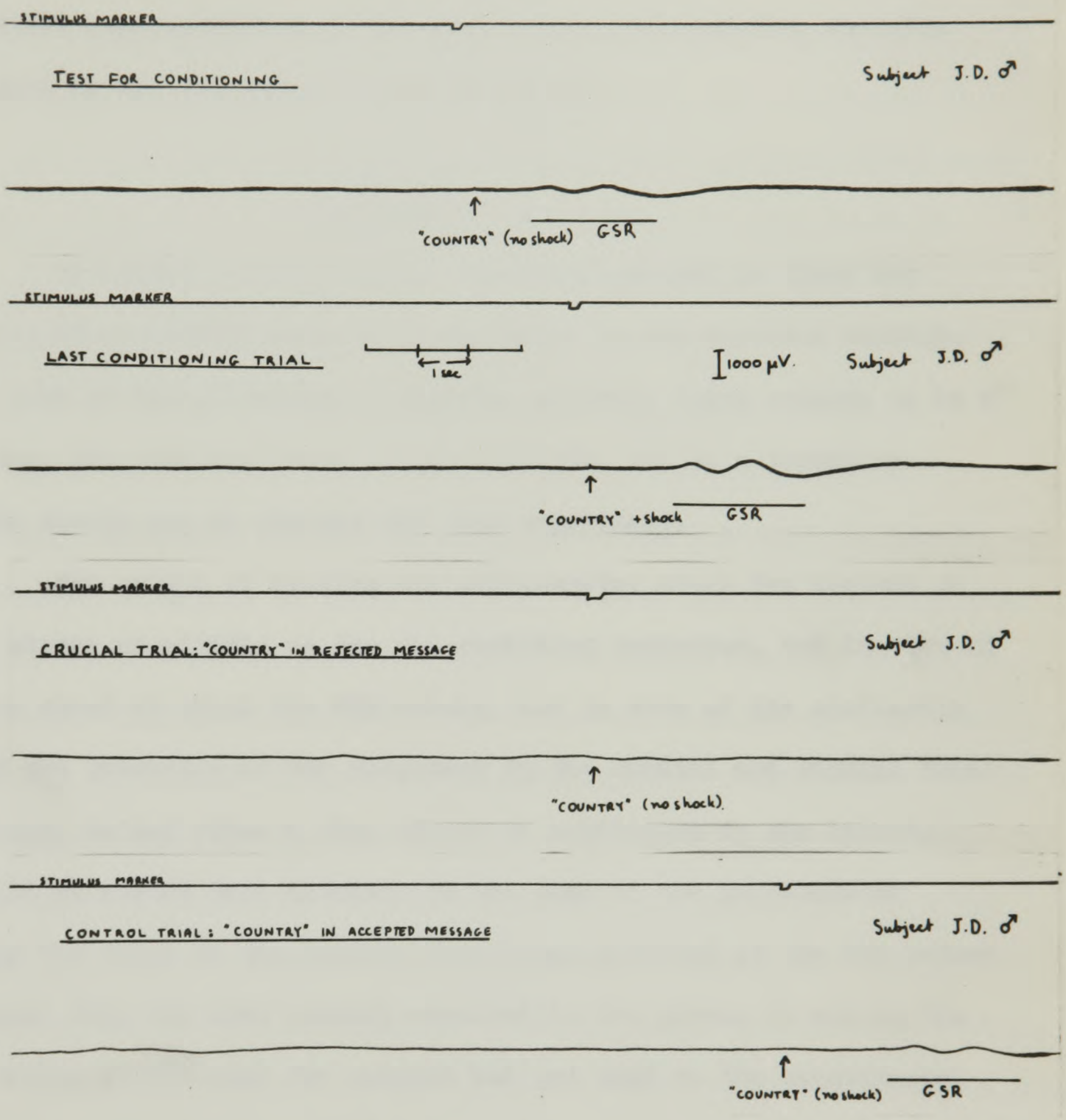

STIMULUS MARKER
TEST FOR CONDITIONING
Subject H.S. ♀
"COUNTRY" (no shock)
GSR
STIMULUS MARKER
LAST CONDITIONING TRIAL
1 sec
Subject H.S. ♀
"COUNTRY" + shock
GSR
STIMULUS MARKER
CRUCIAL TRIAL: "COUNTRY" IN REJECTED MESSAGE
Subject H.S. ♀
"COUNTRY" (no shock)
STIMULUS MARKER
CONTROL TRIAL: "COUNTRY" IN ACCEPTED MESSAGE
Subject H.S. ♀
"COUNTRY" (no shock)
GSR

FIGURE VII b


STIMULUS MARKER
TEST FOR CONDITIONING
Subject J.D. ♂
"COUNTRY" (no shock)
GSR
STIMULUS MARKER
LAST CONDITIONING TRIAL
1 sec
1000 μV.
Subject J.D. ♂
"COUNTRY" +shock
GSR
STIMULUS MARKER
CRUCIAL TRIAL: "COUNTRY" IN REJECTED MESSAGE
Subject J.D. ♂
"COUNTRY" (no shock)
STIMULUS MARKER
CONTROL TRIAL: "COUNTRY" IN ACCEPTED MESSAGE
Subject J.D. ♂
"COUNTRY" (no shock)
GSR

All the GSR's of the first test trial, (COUNTRY in the rejected message), are shown in Figures (VI) and (VII). The first of these is a graphical representation of the moving spot galvanometer, records; the second is the pen recording method result.

Discussion

In neither of the two pen recording records is there any sign of a CR to COUNTRY when it is presented in the rejected message. In the case of the galvanometer records, however, there appears to be a CR in two, and possibly three of the subjects, and so a tentative positive result may be claimed for this experiment.

The method of reading the galvanometer every two seconds is not of course as reliable as the pen-recording technique, but in view of the slow speed at which the GSR occurs, and in view of the similarity between the latencies of the responses in the crucial and control trial recordings, we may place a fair amount of confidence in the latter. It should be stated that although in the case of the galvanometer readings the level of the general background activity of the GSR before the moment when the word country occurred is not given, it was on the whole fairly stable once the subject had got used to the experimental situation: subjects whose GSR's fluctuated greatly from moment to moment were rejected, and it is for this reason that the third CR is doubtful.

All the subjects were questioned at the end of the experiment to discover whether they had been aware of the word COUNTRY in the crucial passage, and all said that they had not.

What may we conclude from these results? Certainly that as had already been suggested it is extremely hard to make a stimulus become

important artificially. By no means all of the subjects responded to their own names all of the time in Experiment (6) and here only two, possibly three out of 10 subjects were successfuly conditioned. It would seem that there are very few stimuli which can break down the barrier set up in selective listening in this way. Probably some would be found if besides the subject's own name, the names of husbands or wives, girl-friends or boy-friends, and suchlike stimuli were introduced into the rejected message.

The theoretical importance of this experiment is that it throws light on the level at which the block in shadowing must be occurring. Both from the conditioning experiment and from the one on the subjects' names, it is clear that some sort of pattern analysis, at least for a few stimuli, occurs at a level below the level of conscious perception. Further evidence to this effect is provided by some more recent work by Oswald, Taylor, and Treisman (1960). They played tape recordings of names to subjects who were asleep and recorded EEG's from them. They found evidence that apart from a greater tendency to awake to their own than to control names, subjects also showed more marked K-complexes, and (at certain depths of sleep) greater GSR's without waking up. One subject even gave specific GSR's to the name of a recently acquired girl-friend, as was suggested above. Both these studies throw light in particular upon the neurological mechanisms involved, and we shall return to this problem in a later chapter. For the present, it is necessary to look at what they imply for the model which was suggested in the previous chapter. What modifications are needed to the form in which it was put forward there?

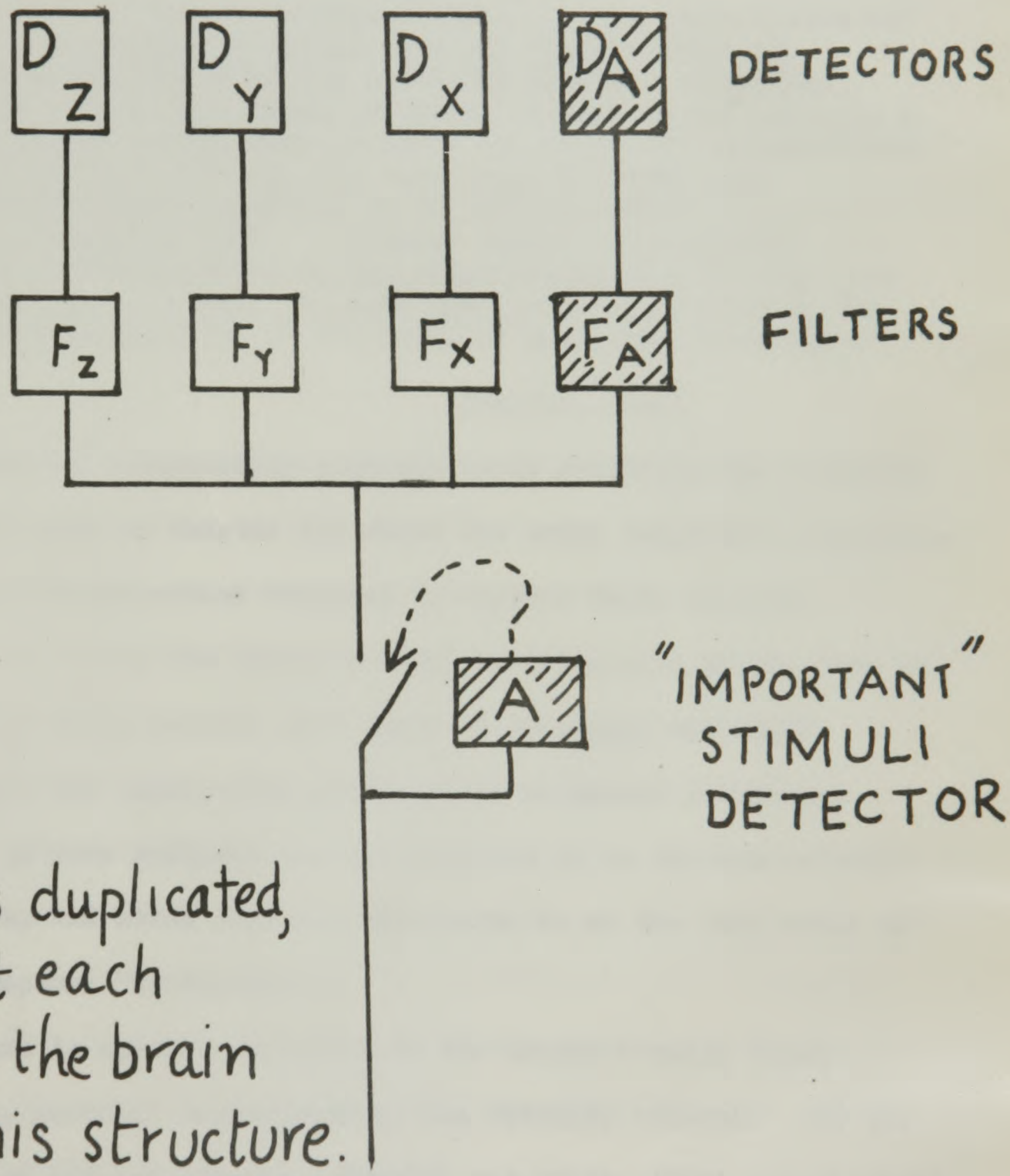
The supposition that a person's own name would break through the barrier set up in dichotic shadowing was confirmed. This in itself raises the problem of howthis recognition is achieved, a problem which might be called the "identification paradox", and described thus: that while the subject is unaware of the verbal content of the rejected message, none-the-less he knows that his own name has been spoken.

Taylor (1960) has recently suggested a model for multi-channel listening which possesses many of the features required of such a mechanism. In her discussion she quotes a model suggested in a personal communication by the writer, but it seems now clear that the latter will not do.

Taylor suggested the whole of the input to the rejected ear is equally attentuated. No selective pattern analysis is done at a level below that at which under normal conditions stimulus would be consciously perceived. At that level the pattern analysis mechanism has some units of lower threshold than others, and the stimuli corresponding to these may be recognised anyway despite the attentuation. The pattern analysing mechanism is, it is suggested, of the type which Utley has described (Utley, 1958).

The writer had suggested a model whose flow diagram is shown in Figure VIII. It consists of a pattern analyser which is represented as a set of tuned filters (F) followed by a set of detectors (D), and preceded by a switch. There are a few stimuli which are picked out by another mechanism at a lower level in the system in such a way that they can operate on the switch and so "capture the attention"; these are the "important" stimuli and the low level analyser is represented by the box labled "A". Taylor argued that the model was a "Double dictionary"

FIGURE VIII



This is duplicated, so that each side of the brain has this structure.

model on the grounds that if this lower centre were to do all that was required to cover the data which we have now accumulated on the subject of selective listening, it would have to reduplicate completely the higher set of analysers. She said:

> "Either of the two (theories which she has been discussing) seems a more economical system than any reduplication of analysis before and after the selective system. Something along these lines also seems necessary to explain why not only a few "important" words, such as one's own name, may be heard from the rejected ear, but also any word which has been made contextually highly probable, or in specific cases . . . . . by instructions or "set". If Moray wanted his suggested analysing mechanism prior to the selective barrier to cope with all these possibilities, it would need to be as complex as the one he places after it, at the level of conscious perception."
>
> (Taylor, 1960)

Now the problem of contextually probable words switching the attention has been dealt with in Chapter III where the cross comparison mechanism has precisely the properties required to explain those results. Taylor seems to regard the writer's model as being more simple than it is. It is virtually certain that there is no single mechanism responsible for the complicated phenomena of selective listening. The specific pattern analyser was not intended to be the maid-of-all-selective-work, and hence does not required to be on the same scale as the main perceptual "dictionary".

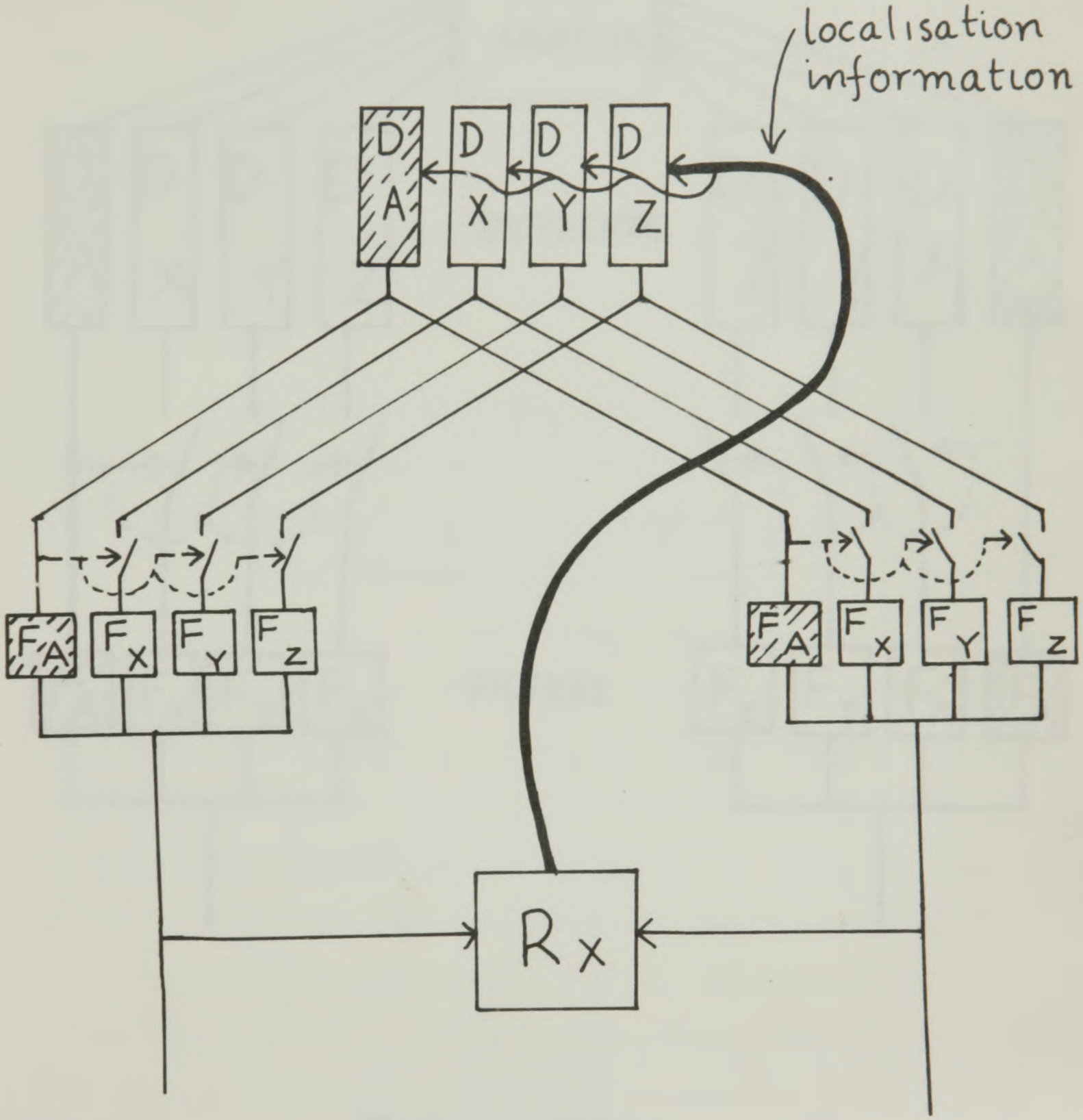
There is another objection to the writer's model which Howarth (1960, personal communication) has recently offered. On the basis of one of his experiments, (Howarth and Ellis, 1960, unpublished), he has found a strong reason to apply Occam's razor to the low level analysing system. Howarth and Ellis determined the thresholds of intelligibility for their subjects' own names and compared them with

the thresholds for other names, much as Oswald, Treisman, and Taylor (1960) had done for sleeping subjects, but this time for subjects who were awake. Howarth argued that if the differential threshold were no greater in the writer's dichotic situation than in Howarth and Ellis's binaural one, then there was no need to postulate an extra "block" to alter the threshold still further. By comparing the data from Experiment (6) above with his own data, he was able to show that there is probably rather little difference between the two, which favours his interpretation of the situation: that changes in the threshold of a central analysing mechanisms are enough to account for the results, without postulating a peripheral block as well.

A more serious objection however, is that the writer's model can cope only with a truly dichotic situation, and not one where there are more than two inputs: for example, as shown in Figure VIII it would need to multiply the filter/detector banks to match the number of distinct input channels, and this will clearly not do, since input may be multichannel at each ear. This point draws attention, though, to a deficiency in the present design of Taylor's model - namely, that even if there is only one central bank of detectors, as she has suggested, none the less the subject knows which of the channels he is listening to (usually). In a dichotic shadowing situation, he does know that the name "was on the other ear", and the model she offers, in its present state, does not seem to cater for this.

There are two ways in which the preservation of the localisation information in the signal might be done by the brain. In the first place, the auditory localisation correlator low down in the pathways, (R_x) in the model in Chapter III, might transmit signals to

FIGURE IX (a)



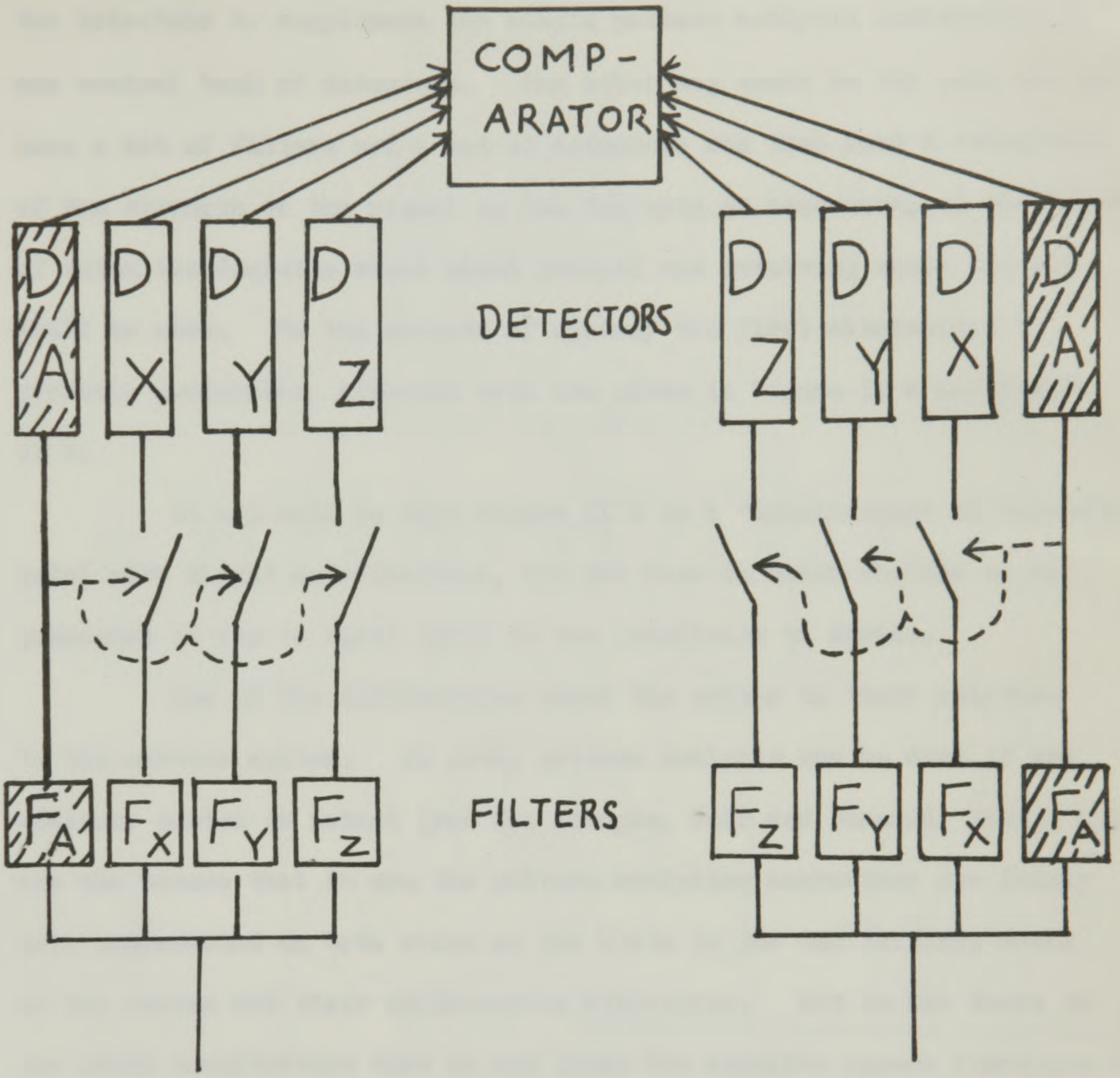

COMP-
ARATOR
DETECTORS
D A
D X
D Y
D Z
D Z
D Y
D X
D A
FILTERS
F A
F X
F Y
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F Z
F Y
F X
F A

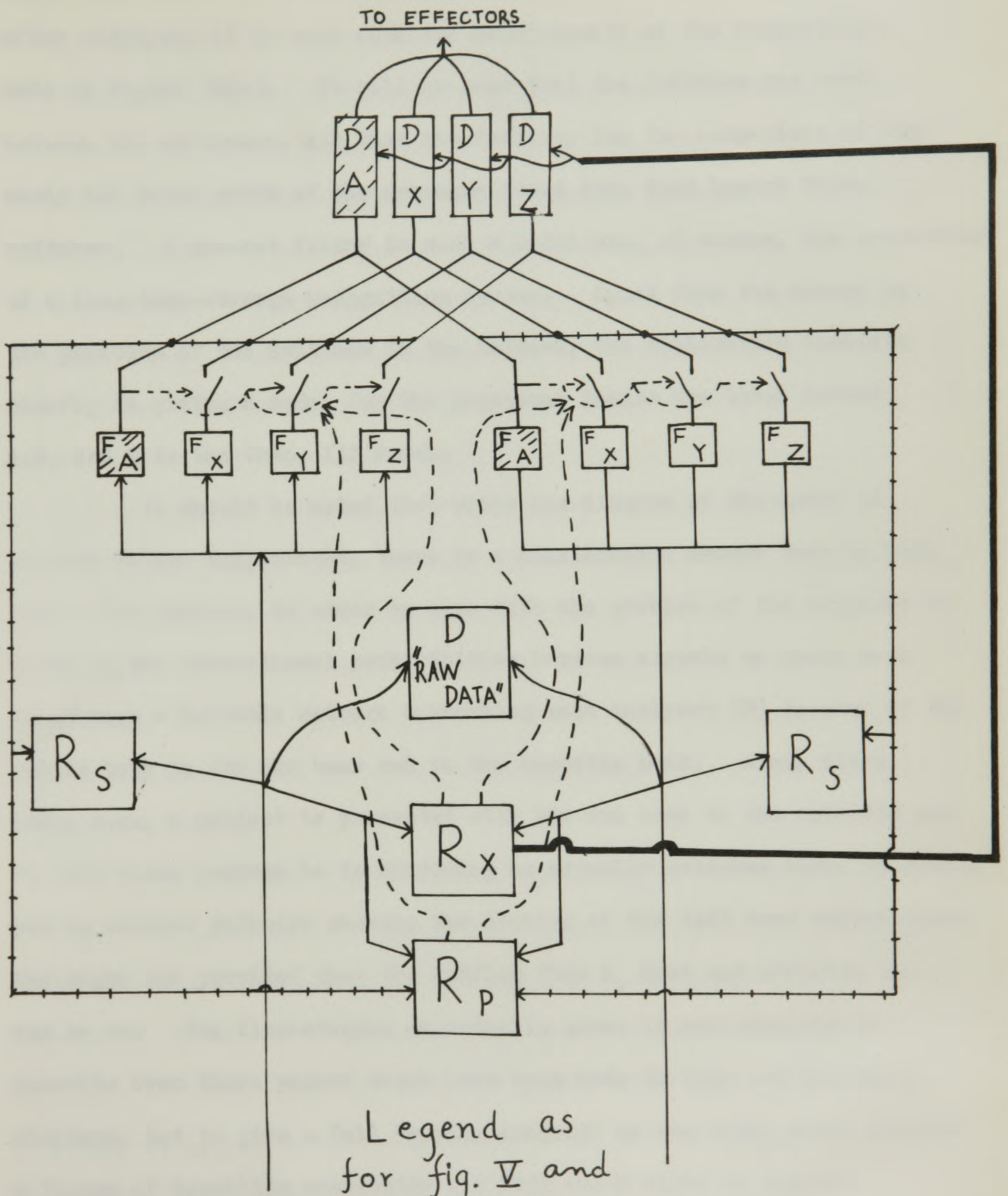
FIGURE IX (6)

the detectors to supplement the simple pattern analysis information in one central bank of detectors. The other way would be for each ear to have a set of filters and a set of detectors and then have a comparison of the strength of the signal in the two sets of detectors, on the basis of which the decision about which channel was receiving which signals could be made. On the grounds of economy the first alternative is probably preferable, although both are given in Figure IX a and Figure IX b.

It may well be that figure IX a is a "translation" of Taylor's model with slight modifications, but the form in which she has so far presented it (up to April 1960) is too indefinite to decide.

One of the difficulties about the models is their relation to the nervous system. In cats, pattern analysis can be done if the auditory cortex is intact (see for example, Neff and Diamond, 1958), and one can assume that in man the pattern analysing mechanisms are fairly well represented on both sides on the brain in the two Auditory areas of the cortex and their neighbouring structures. But in man there is the added complication that by and large the specific speech functions are unilaterally present, and the bearing of this difference between speech areas, auditory cortex, and also the temporal lobe and parietal lobe "aphasia areas" such as Penfield (1959) has indicated, needs a great deal of work. At present it seems, however, safe to say that a model similar to those just discussed will probably be found adequate to cope with the data which we now possess, although such a model will need to be presented in much greater detail than has been done either by Taylor or the writer.

FIGURE X



Legend as for fig. V and fig. IX

Figure X represents the model presented in Chapter III after modifying it to cope with the requirements of the suggestions made in Figure IX(a). It will be seen that the switches now come between the analysers, and that the feedback for the comparison of the early and later parts of the messages comes from just beyond these switches. A pre-set filter in such a model has, of course, the properties of a long-term-storage recognition system. Apart from the change in the position of the switches in the network, the elaboration consists chiefly in giving a model for the processes inside the boxes labled A,P, and M in the Chap. III model.

It should be noted that while the diagram of the model is already rather complicated, there is a considerable amount that is left out. For example, in order to cope with the problem of the response in terms of the transitional probabilities between signals we would have to arrange a suitable network connecting each analyser (F) to each of the others both in its own bank and in the opposite bank. Also, since when, e.g., a subject is presented with his own name in the opposite ear to that whose message he is shadowing he actually switches ears, we should put in control pathways whereby the closing of the left hand switch opens the right one provided that the outflow from R_x does not override it, and so on. The flow-diagram as actually given is not adequate to describe even those points which have been made in this and preceding chapters, but to give a full "wiring diagram" of the model would produce a Figure of appalling complexity - a fact which might be thought encouraging and suggestive that the present model may not be excessively distant from the true one. Figure X is to be taken as a

first approximation to the complete model.

Suppose that the subject is listening to his right ear. The switches on that side (between the filters and the detectors) will be closed, and those on the opposite side will be open. Thus he will hear the words which arrive along the right hand pathways, and his behaviour will be as predicted on the basis of the model as described in Chapter III. If now an "important" stimulus arrives along the left hand pathways, it will pass straight from the filter to the detector which is set for it, since for such stimuli there is no block. (The filters and detector for these stimuli are hatched in the diagram). It will be perceived, and also by the control pathways which leave its input pathway between the filter and the detector, it will close all the switches on its own side of the auditory system, and (by means of pathways which have been omitted from the diagram for the sake of simplicity) open those on the opposite wide. Thus the subject will switch attention to the left hand input following the arrival of the important stimulus.

Since in practice he returns (usually) to the right hand message, this interruption appears to be only temporary, and the "bias" introduced from the higher centres reasserts itself after a short interval. These timing relations, the relative strengths of the different factors operating, etc., are points about which we have virtually no information at present,so it has not been attempted to incorporate them in the model at this stage.

CHAPTER V

Questions of Timing and the Switching of Attention

"..... Wanton will with change delighted."

(John Forde, 17th Century Madrigal)

The early studies of this problem, from the time of Titchener up to the end of the second world war were almost all concerned with the switching rates between visual tasks, or in successive motor responses, using stereoscopes to measure the effects of binocular rivalry, or tasks such as those of Bills (1935) in the latter case.

Almost without exception, however, these results do not yield data which can be used to assess the time taken to switch attention. In the cases of binocular rivalry, or the fluctuation of ambiguous figures a switching <u>time</u> (as against a switching <u>rate</u>) could only be estimated by deducting the time during which either one or the other stimulus was visible from the total time, and this seems never to have been attempted: which is hardly surprising. Bills' work naturally ties up with all the subsequent work on the "psychological refractory period", but here the sort of explanations which have been given seem to take us away from, rather than towards, the problem of the time taken to switch attention.

Since 1950, however, there have appeared a new series of experiments, this time in the auditory field, which have been aimed, sometimes explicitly, sometimes only en passant, at this problem.

A review of the literature leaves the impression that apart from these there is very little that is really relevant, so it is only on these studies that we shall turn our attention.

Many of the modern experiments are due to Broadbent, whose work has arisen out of the very practical questions associated with the maintenance and switching of attention: for example the problems of air traffic control where a man may receive several simultaneous or nearly simultaneous messages and be required to give correct answers to all of them. The most relevant of his experimental work is that published in 1954, under the title "The role of auditory localisation in attention and memory span." He investigated the following situation.

The subject listened to groups of digits in random order which were delivered through headphones, dichotically. The digits arrived in pairs, one digit to each ear simultaneously. A group of three pairs was presented to the subject, who was then asked to recall them. Broadbent found that if the subjects were allowed to recall all the digits from one ear followed by all those from the other ear, then they could perform with a high degree of efficiency even if the rate of presentation were two pairs of digits per second. But if the subjects were required to alternate between the ears, so that the order of recall was "left - right - left - right - left - right" - which he referred to as responding in the correct order of the signals' arrival, then the subjects could not perform efficiently if the signals arrived faster than one pair every 1½ to 2 seconds. He discussed the reason for this difference, and suggested that when the subject has to "switch" from ear to ear in the latter condition the maximum rate at which he can

switch is such that when signals arrive faster than 1 per ear per 1½ seconds it is impossible for the subject to comply with the experimenter's instructions. In discussing the connexion of this experiment with one by Cherry and Taylor, he said:

> "This is not an unduly different estimate from the one given earlier: two shifts would then take 1/3 of a second, and if the perception of a digit takes ½ second this would give 1 1/3 second for the whole cycle of shifting between ears. Remembering that naval ratings are probably slower than most laboratory subjects, this is not too different from the time of 1½ - 2 seconds found in the memory span experiments."
>
> (Broadbent, 1958; pp. 213, 214)

The experiment of Cherry and Taylor's to which he was referring was the following (Cherry and Taylor, 1954). They presented prose to subjects who heard it through earphones. The speech came through either the right or the left earphone at any moment, and they investigated the effect of switching the message backwards and forwards between the ears at various rates. They found, measuring the intelligibility, that there was a marked drop at a switching rate of round about 3 cycles/sec. They suggested that the reason for this is that the subject takes 1/6 of a second to switch from one ear to the other, so that at this rate of switching of the message he does not "arrive at" the opposite ear in time to hear anything. Now Broadbent himself, although taking the trouble to compare his findings on switching rate with those of Cherry and Taylor, points out that there are reasons for doubting this interpretation. Not the least of these is the fact that if the message is merely turned on and off in one ear, (not switched between the ears - merely an interrupted monaural message), the same dip in intelligibility is found at this rate of interruption. Clearly this cannot be due to a mechanism which switches between the ears.

Broadbent suggests that the dip is due to the sampling period of the brain being about 1/3 second, so that at this rate only 50% of the signal is sampled with resulting loss of intelligibility due to inadequate information on which recognition decisions can be made. A similar alternative explanation could be offered as follows, where not the sampling period of the organisms, but simply the structure of the signal is invoked. The average duration of a single syllable is of the order of 1/4 second or more when speaking at a rate of about 120 words or so a minute. It might be that the information points in the phonemes were such that at a rate of switching such as that used by Cherry and Taylor these were particularly badly "damaged" - (it would mean just over one interruption per syllable) - and that is why the intelligibility goes down. Support for a view such as this, or for the explanation offered by Broadbent is given by the fact that when Cherry and Taylor used a lower syllabic rate the dip in intelligibility tended to disappear.

Thus we are left with Broadbent's original experiment as the sole source of data on which to decide what the rate of switching of attention is. From it it would appear that it takes about 1/6 of a second to transfer the attention from one ear to the other.

But is it in fact, sufficient to establish this conclusion?

It is clear that there are several assumptions which are implicit, and some explicit, in Broadbent's account of what is happening. Firstly, what is the time for a "perception of a digit"? Can we really feel happy that this is ½ second? The average rate of speech in normal conversation, or in reading aloud, tends to be 120 words a minute at

least. This gives a syllabic rate of (very roughly, and assuming an average word length of about 2 syllables a word - a not unreasonable assumption), 240 syllables a minute without allowing for pauses. Now of course we do not know how much of a syllable a person makes use of in listening to speech. Probably it is nothing like the whole of the signal, since Shannon (1949) has shown that ordinary English speech is over 50% redundant. But even supposing that the whole syllable is used in identification, this gives a "perception time per syllable" of about $\frac{1}{4}$ rather than $\frac{1}{2}$ second. But, it might be argued, Broadbent was speaking more slowly, so that perception took longer. Then the perception time varies with the rate of speech? If so, which value are we to assume when calculating the switching rate?

Experimentally, the dilemma may be underlined by quoting the following experiment.

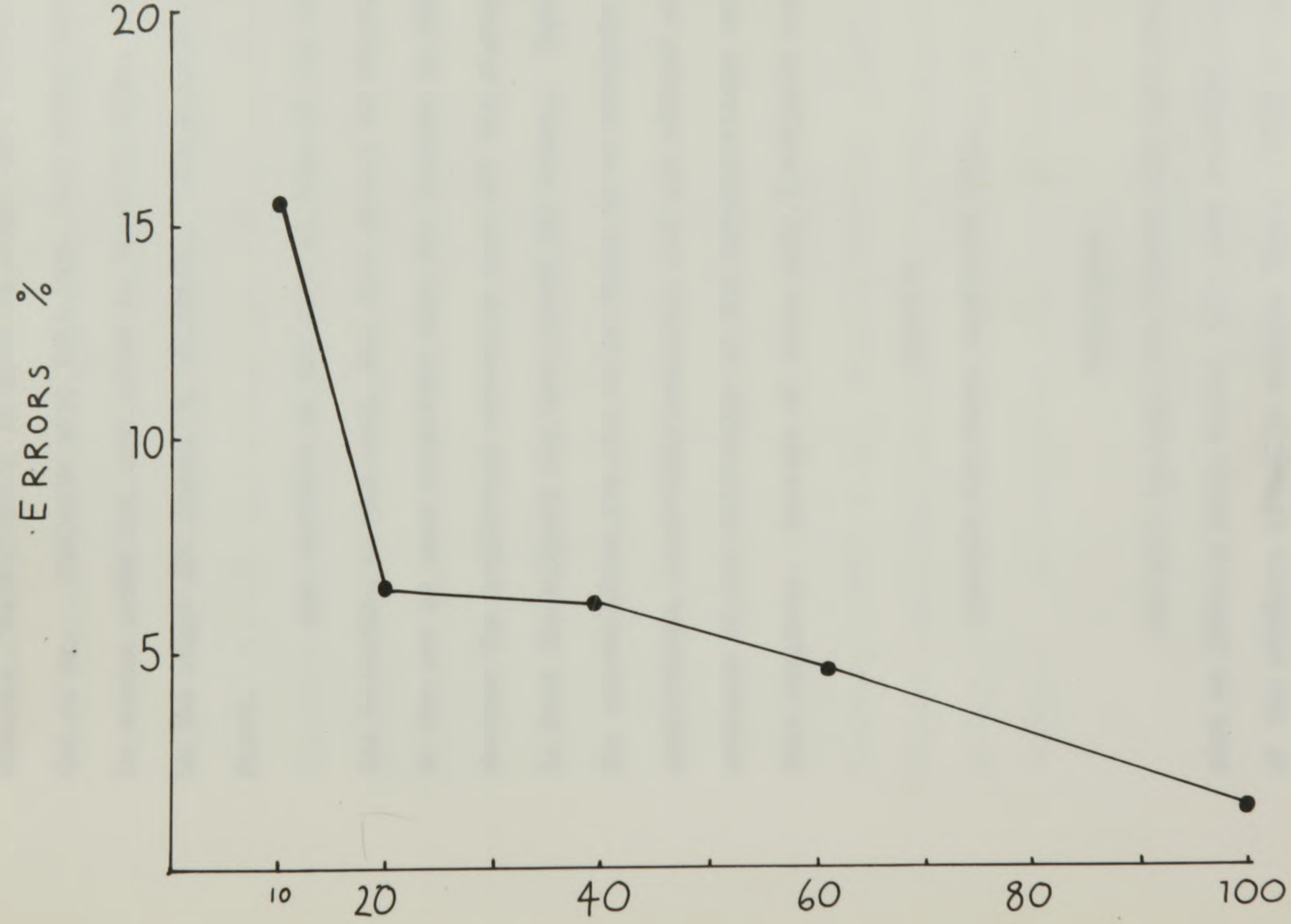
EXPERIMENT (10)

Duration of signal necessary for digit recognition

Method

An "electronic guillotine", designed by P. Dawe of the Oxford University Institute of Experimental Psychology, was used to cut off the signal a known time after it began. A series of digits 0 - 9 was recorded in random order on magnetic tape and played through a loudspeaker to subjects who sat about twelve inches in front of the loudspeaker. The guillotine was triggered by the beginning of the signal, and interrupted the signal after an interval of 5 - 500 msecs.

FIGURE XI


20
15
10
5
% ERRORS
10
20
40
60
80
100
DURATION OF SIGNAL : MILLISECS.

Thus the subjects heard only the first part of any signal. For example, "seven" could be made to sound like "seven", "seve", "sev", and so on. Subjects were told that they would hear digits 0 - 9 in random order and were asked to identify them. The times used were in the range 250 msecs. to 20 msecs. The longest durations were given first.

One variable is the rate of rise of the signal intensity at the beginning of the word, and this cannot be controlled. For example, if the ear is more sensitive than the trigger on the guillotine, then whereas the guillotine nominally cuts off the signal after, say 100 msecs., in fact the subject may have heard 120 msecs. Because of this difficulty the values given are not to be taken as an absolute limit of the subject's performance, accurately measured, but are offered only as additional evidence of the difficulty of the determinations being discussed in this chapter. Because of this, only 3 subjects were used.

Results

Results are shown in Figure (XI).

Discussion

It will be seen from Figure (XI) that subjects are extremely good at judging which signal they have received even though very little of the stimulus actually reaches them. This is understandable, since the initial phonemes of the digits "oh" to "nine" are in most cases all that is necessary for the identification of the digit: the only exceptions are the "f" of four and five and the "s" of six and seven.

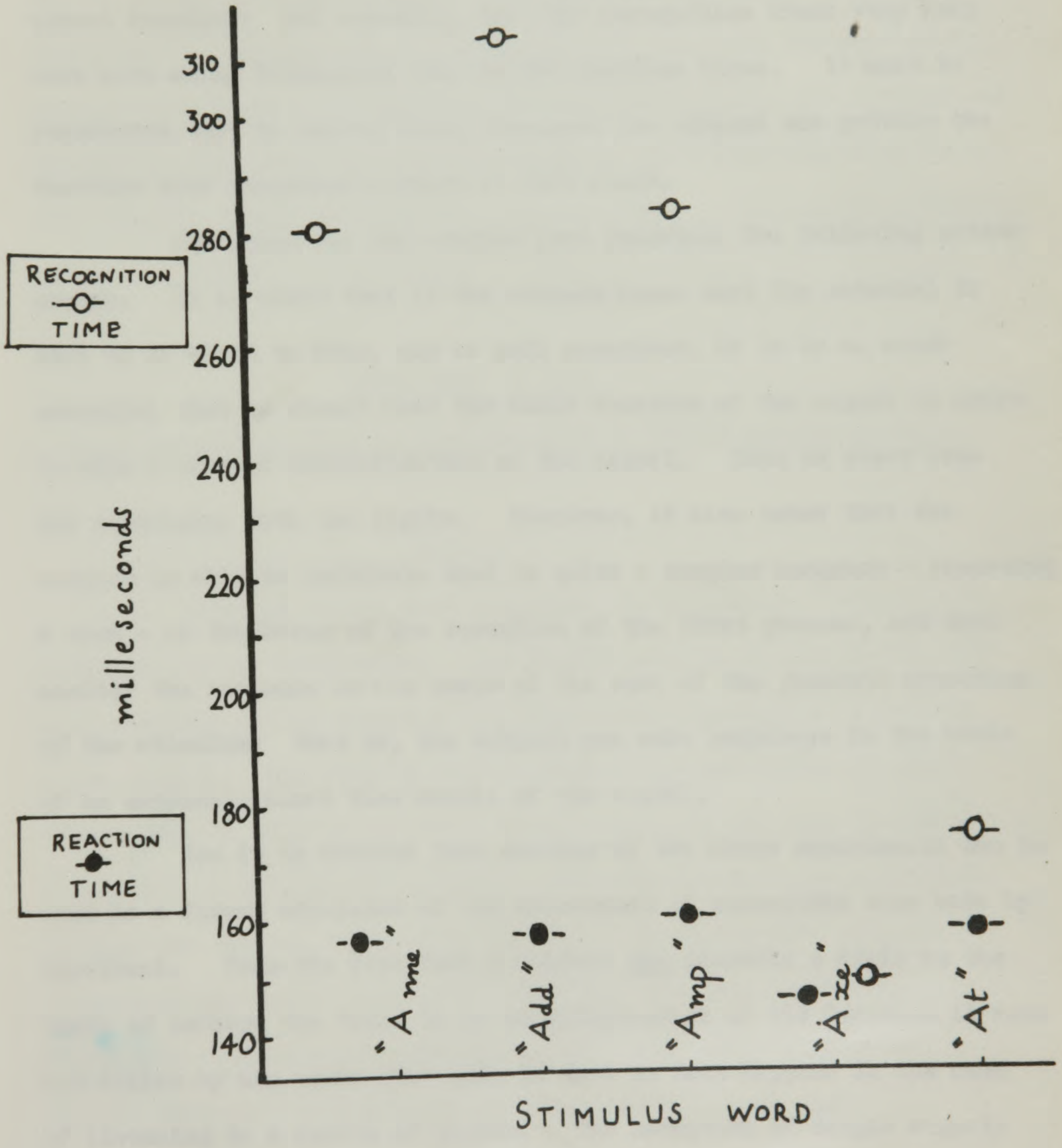
In another part of the investigation from which the above experiment is taken (Davis, Taylor & Moray; 1960) a comparison of recognition time and reaction time was made using the same technique to find the recognition time. The subject, whose name was "Anne", could hear one of the following five words: "Anne", "Add", "Amp", "Axe", or "At". In this case in each case the initial phoneme is the same. In the first part of the experiment, the subject was simply required to say which of the words had been presented, and as before the end of the words was progressively "tail-clipped" by the electronic guillotine. In the second part of the experiment, the subject listened to the words through headphones, and repeated each word out loud as fast as possible, but with the experimenter insisting that she must get them all correct. The "audio-verbal" reaction time was measured in this way to the five words. The initial signal arriving from a tape recording through the headphones was used to start a "Dekatron" timer, and the subject's response, picked up by a throat microphone, stopped the "Dekatron". Various corrections were applied to the timings, as described in Davis et al., (op. cit.) and the reaction times and the recognition times compared. The results are given in Fig. (XII) and Table (XV).

Table (XV)

Reaction times and Recognition times for verbal stimuli

Word	R.T.		Recog. Time	
	Mean	s.e.	Mean	s.e.
Anne	155	7.2	280	
Add	155	5.6	310	
Amp	157	8.3	280	
Axe	147	7.7	150	
At	156	3.3	170	
pooled	154 msecs.	5.7 msecs.	240 msecs.	not available msecs.

FIGURE XII


310
300
280
260
240
220
200
180
160
140
milleseconds
RECOGNITION TIME
REACTION TIME
"A me"
"Add"
"Amp"
"Axe"
"At"
STIMULUS WORD

Discussion

Two points are apparent from this data: firstly, that the reaction times are very much shorter than the recognition times, and almost constant; and secondly, that the recognition times vary very much more among themselves than do the reaction times. It must be remembered that in making these responses the subject was getting the reaction time responses correct at that speed.

Combining the two studies just reported, the following points emerge. It is clear that if the subject knows what the material is that he is about to hear, and is well practised, it is by no means essential that he should hear the whole duration of the signal in order to make a correct identification of the signal. This is clear from the experiment with the digits. Moreover, it also seems that the subject is able to inititate what is quite a complex response - repeating a word - on the basis of the reception of the first phoneme, and then monitor the response on the basis of the rest of the phonemic structure of the stimulus: that is, the subject can make responses on the basis of an extremely short time sample of the signal.

Now it is obvious that neither of the above experiments can be used as a direct criticism of the assessment of perception time made by Broadbent. From the fact that a subject <u>can</u> identify a digit on the basis of perhaps the first 50 or so milleseconds of its duration it does not follow by any means that this is what in fact happens in the case of listening to a series of digits. The reception of single signals and the reception of a multiple series of signals occurring in time is a very different matter, as Broadbent has rightly observed (personal communication). But these data do raise the point that the whole idea

of "how long a perception takes" is a very peculiar one, and likely to give rise to very different answers according to the circumstances in which the measurements are carried out.

Now it might be argued that at least in the case of the experiment as carried out by Broadbent, that is, when the subject is presented with pairs of dichotic, simultaneous, digits, the estimate of perception time which he gave is adequate: that subjects do in fact, need about $\frac{1}{2}$ second to perceive a spoken digit. However, the following experiment casts doubt on this.

EXPERIMENT (11)

Digit perception time in response to a series of spoken digits

Method

Lists of digits were prepared, and presented binaurally to subjects through headphones. The digits were in groups of six, and were randomly chosen from 0 - 9. They were presented at a rate of 4 per second. The subject was required after each group of six to repeat back as many as he could. The groups of six came at ten second intervals, in sets of ten groups. The subjects were not practised, as this run was the first of a series, of which the rest will be discussed below under a different heading, and this condition was originally used as a practise session for the later conditions. Sixteen subjects, students and research workers, were used.

Results

Mean errors per 10 groups of six digits = 3.0 s.e. = 0.7

Discussion

If the mean number of errors for a whole run of 60 digits (in ten groups of six) is only 3.0, then it is clear that since they are being presented at a rate of 4 per senond the time for a "perception" cannot be taking anything like $\frac{1}{2}$ second. Indéed it seems that the time taken to recognise a digit must be substantially below $\frac{1}{4}$ second; for if it approached this value we would expect to find that the average number of errors was considerably higher. What now becomes of any attempts to estimate "switching time" from the combination of "perception time" and "switching time"? It seems that the suggestion made above is substantially correct: use shorter signals and quite new values may appear.

There is another comment, however which can be made about Broadbent's design. In his original paper, Broadbent remarked that at the high speeds of presentation, the subjects could not recall the digits in the correct order of arrival, since they could not give the alternating response (left - right - left - right - left - right). But this is not, strictly speaking, the correct order. If we are really going to speak of the "correct order" it can only be that order in which the subjects originally received the stimuli. This is not (left - right - left - right - left - right), - which will from now on be abbreviated to LRLRLR - but $\begin{pmatrix} \text{left} & \text{left} & \text{left} \\ \text{right} & \text{right} & \text{right} \end{pmatrix}$; and of course the subject cannot recall in this order without saying two things at once! Moreover, as has been pointed out, (Taylor, A., personal communication), if the subjects are switching in the way which Broadbent suggests, they are not switching between a stimulus and another stimulus,

but between a stimulus and the short-term memory trace of another stimulus, and this in itself may make for complication in assessing the causes of the inability to give the RLRLRL form of recall at high speeds.

Because of this, the following experiment was designed with the idea, initially, of presenting stimuli in such a way that the subject could switch directly between the stimuli, not between a stimulus and a trace. In the discussion it will be shown that in fact thedesign is faulty in respect of fulfilling this purpose, but the results are of intrinsic interest in the light of the above discussion.

EXPERIMENT (12) *

A study of the effects of different conditions of presentation and recall, and different rates of presentation, upon the accuracy of recall in a dichotic listening situation

Method

Lists of six digits were prepared, and presented to the subjects in groups of six digits. There was a ten second pause between each group during which the subject had to recall the digits he had just heard. A Brennell Mk. IV two-channel tape recorder was used to present the stimuli to the subject through headphones, which were Brown Type K, moving coil, low impedance phones. Subjects were asked to recall the digits either in any order they liked, (free recall); or all the digits from one ear followed by all those from the other, (successive recall,

* This experiment has in part been given in the previous chapter (p. but is here repeated for the reader's convenience in its full form.

LLLRRR); or by switching from ear to ear, (alternate recall, LRLRLR). A binaural condition was also used, in which case the stimuli were obtained by mixing the two dichotic inputs in a mixing box before they went to the headphones. All the free recall conditions were given before either the successive or alternate recall conditions were given, so that the former functioned as practise trials for the latter two conditions. The dichotic presentation conditions were as follows: Simultaneous (= = =) at 2 signals/second; staggered (-·-·-·) at 2 signals/ear/second; and Slow overlapping (——_——_——_) at 1½ signals/ear/second. Half the subjects received the staggered before the alternate signals, and half vice versa. 16 subjects were used, undergraduates and research workers between the ages of 18 and 30.

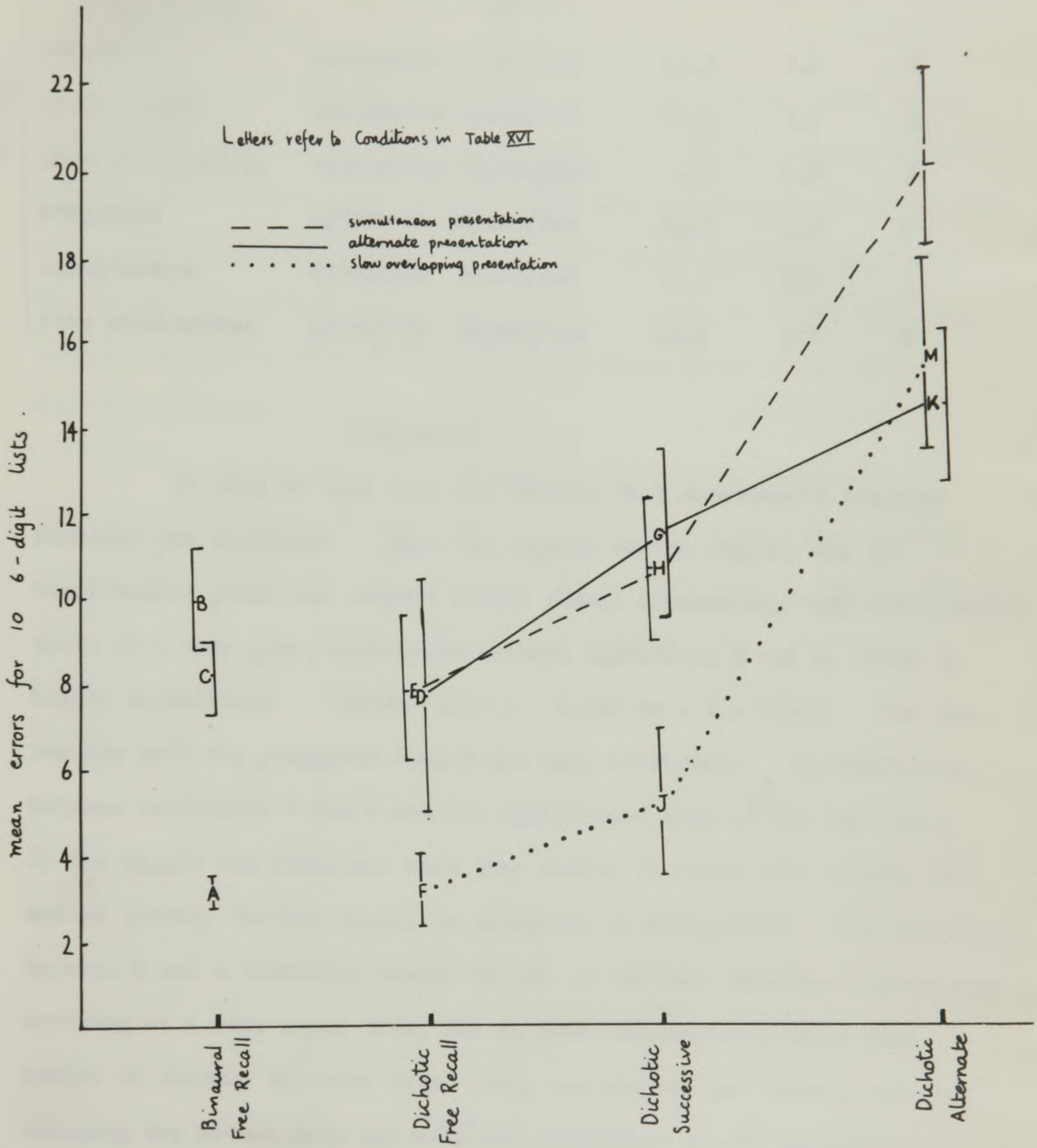
Results

The results, together with the order of presentation and recall etc., are shown in Figure (XIII) and Table (XVI).

Table XVI

Presentation	Recall	Rate	mean errors per 10 6-digit lists	s.e.	Condition
binaural: successive ------	free	4/ear/sec	3.0	0.7	A
binaural: simultaneous = = =	free	4/ear/sec	9.9	1.3	B
binaural: slow overlapping —— —— —— / —— —— ——	free	3/ear/sec	8.0	1.0	C
staggered _-_-_-	free	2/ear/sec	7.6	2.9	D
simultaneous = = =	free	2/ear/sec	7.7	1.7	E

FIGURE XIII



Errors in recall and standard errors in different recall conditions.

slow overlapping	free	1½/ear/sec	3.1	0.8	F
staggered	successive	2/ear/sec	11.3	2.0	G
simultaneous	successive	2/ear/sec	10.0	1.7	H
slow overlapping	successive	1½/ear/sec	4.9	1.8	J
staggered	alternate	2/ear/sec	13.5	1.9	K
simultaneous	alternate	2/ear/sec	19.9	2.1	L
slow overlapping	alternate	1½/ear/sec	14.6	2.3	M

dichotic

Discussion

It will be seen from the results that Broadbent's original findings are confirmed. When the signals arrive rapidly and in simultaneous pairs the subject cannot recall alternately very efficiently: there is a very great difference between conditions H and L, which is highly significant. (better than $p = 0.001$ on a t - test). But the results with the staggered digits are very different. The difference between conditions G and K are not significant even at the 10% level. If the digits are staggered when they arrive it seems that it does not matter greatly whether recall is alternate or successive. The difference between H and L therefore cannot be due to the fact that the signals are arriving at a very rapid rate, for in both conditions G and K they arrive at exactly the same rate, viz., two per ear per second, and yet changing the recall does not make any difference to the performance. In fact it seems that the increase in errors must be put down not to the rate at which the signals arrive, but simply to the fact that in one condition, the simultaneous, they overlap on the two ears, while in the other, the staggered, they do not overlap. From which we may

conclude that the rise in errors in condition L is an effect of interference, not rate.

It might be argued that the reason why K shows fewer errors than L is because in the former there are at least two digits, the first and the last of each group of six, which do not overlap with any on the other ear, and that therefore this sort of presentation is inherently easier for the subject than simultaneous presentation. But that this is not the case is shown by the fact that there is no significant difference between conditions G and H.

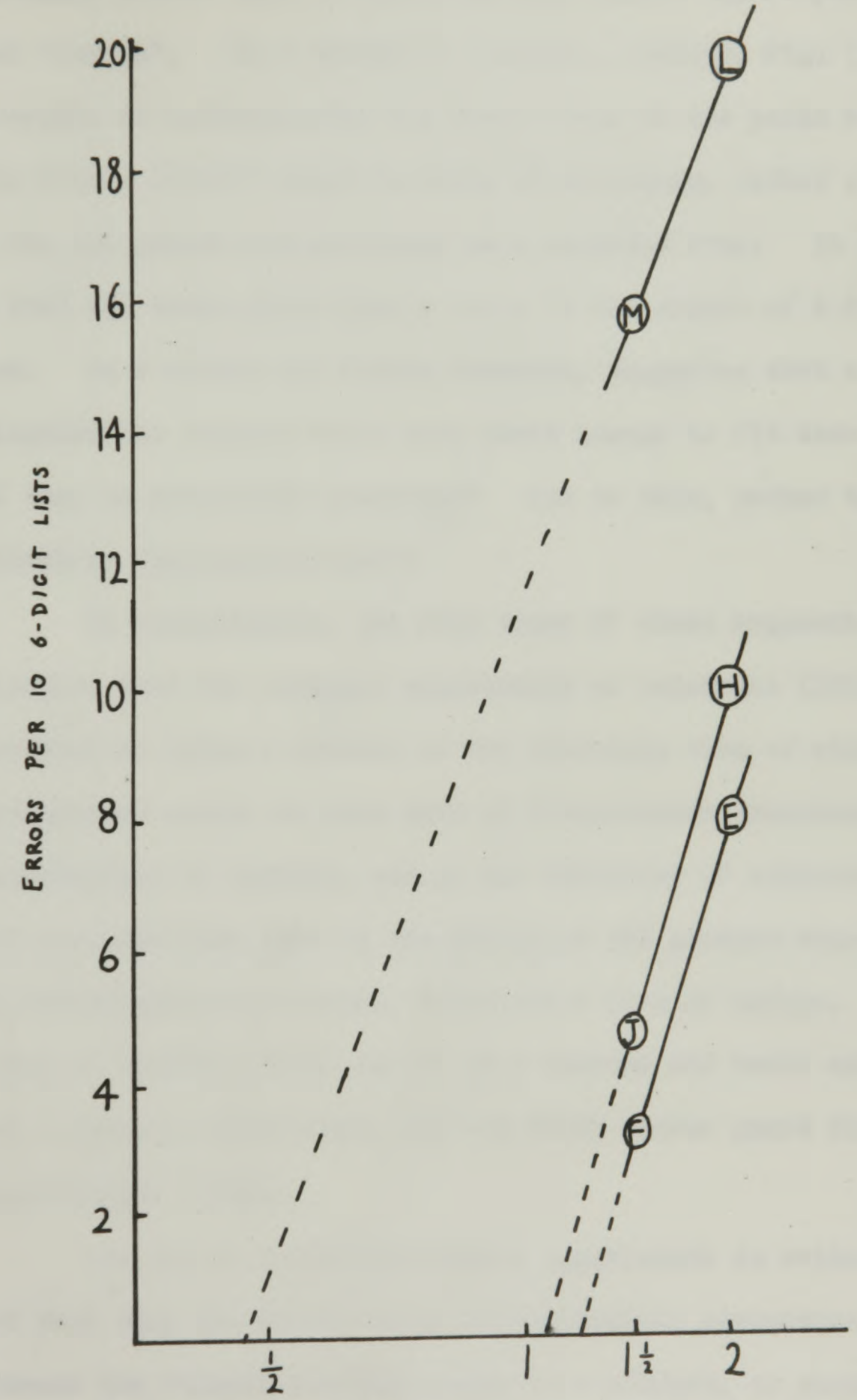
So we are forced to the conclusion that the results that Broadbent found, that at high rates of presentation the subject cannot recall alternately, are due simply to the interference of overlapping the signals, not to the rate at which they are presented. It is not a limit on switching time which he has found, but some sort of interaction.

That there is an effect of rate appears in another way, however. If we consider the graph, we see that there is a remarkable constancy in the distance apart which the two lines maintain which join points on the "slow overlapping" and "simultaneous" plots; (see E - F, H - J, and L - M). Both these conditions present the subject with signals which overlap in time, but the lower plot is of signals which arrive at a slower rate. The difference between D and F, and G and J, are likewise constant, and very close to the E - F and H - J values, which is what we would expect if the change in rate of presentation was responsible for the difference. Only in the case of condition L does this parallelism fail - and here of course there is the additional difference of overlapping versus non-overlapping as well as the difference

in rate of presentation. In comparing condition K with M, in fact, we find that K actually shows less errors than M, although the rate of presentation is greater for K. The difference between these two conditions is not significant at the 10% level, but it is certainly interesting, and can be taken to mean that having to respond to signals which do not overlap is at least as helpful as a considerable decrease in the rate of presentation when recall is to be by alternating between the ears in a dichotic listening situation.

It would seem that the way to assess the effect of rate upon performance is to consider the change in errors between the two plots mentioned in the preceding paragraph. The results of this are shown graphically in Figure (XIV). Here the number of errors is plotted against the rate of presentation of the stimuli. It will be seen that when recall is either Free or Successive, the graphs indicate the same result: that a rate of presentation of about 1 digit per second per ear is the fastest at which a completely accurate response can be given. If we look at the plot for alternate recall, however, it gives a very different value, and there is little doubt that here as well as rate the actual recall strategy is having some effect, for otherwise we would expect all three plots to converge on the same point of the x-axis. The rate of presentation is plotted on a log scale, because it is well known that in any series of experiments where the conditions gradually become easier and easier for the subjects the improvement in performance is most often found to lie along a curve which rises with negative acceleration, and often along an exponential. It is obvious that to draw detailed conclusions from such plots we would require more points on all the graphs: here the main point is to draw attention to the

FIGURE XIV

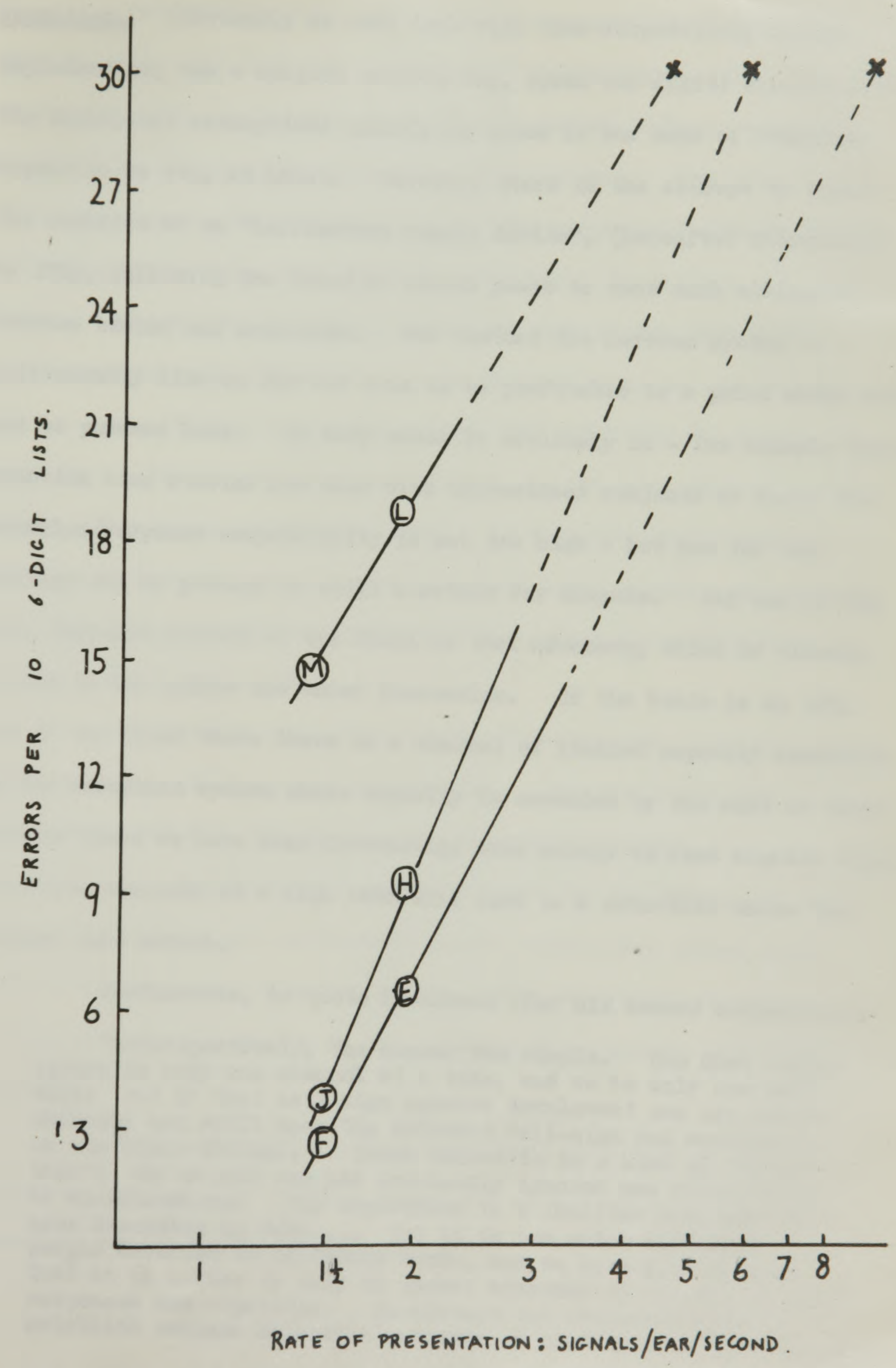

ERRORS PER 10 6-DIGIT LISTS
20
18
16
14
12
10
8
6
4
2
½
1
1½
2
L
M
H
E
J
F
RATE OF PRESENTATION: SIGNALS/EAR/SECOND.

fact that this is the way to discover the effect of rate upon performance rather than by asking at what points the subjects can or cannot "switch". As a matter of interest, however, Fig. (XV) presents the results of extrapolating all three plots to the point at which half of the digits (30/60) would be lost, if we assume, rather gratuitously, that the two points are genuinely on a straight line. It will be seen that all three plots give a value in the region of 6 digits per second. As a matter for future research, supposing that we could find distinguishable signals which were short enough to fit into 1/6 second, would they be accurately perceived? And is this, rather than ½ second, the limit on "perception time"?

To recapitulate, the main tenor of these arguments has been to maintain that the original experiments of Broadbent (1955) which he interpreted as being a measure of the switching time of attention are to be interpreted rather as some sort of interference phenomenon caused by the overlapping of signals, not by the inability of subjects to switch. But it was mentioned that in the design of the present experiment, using non-overlapping signals, there was a flaw of design. The time has come to consider this, for it is a serious and basic criticism of all switching experiments, and one which raises great difficulties of experimental design.

Are any of these experiments experiments in switching? The belief that they are rests upon a methodological assumption - that if we present two stimuli simultaneously to a subject, or successively, (in the case of the experiment just described), and they are presented over what superficially appear to be two different "channels", then the subject must respond by dealing with them successively <u>during</u>

FIGURE XV


30
27
24
21
18
15
12
9
6
3
ERRORS PER 10 6-DIGIT LISTS.
L
M
H
E
J
F
1
1½
2
3
4
5
6
7
8
RATE OF PRESENTATION: SIGNALS/EAR/SECOND.

reception. (Obviously he must deal with them successively during reproduction, for a subject cannot, e.g. speak two digits simultaneously.) The conceptual assumptions underlying these in the case of Broadbent appear to be two, at least. Firstly, there is the attempt to treat the organism as an "information theory device", (hereafter abbreviated to ITD), following the trend of recent years to draw such analogies between brains and artifacts. Now whether the nervous system is sufficiently like an ITD for this to be profitable is a point which will not be pursued here. In many cases it obviously is - for example where reaction time studies are done with unpractised subjects or where the stimulus/response compatability is not too high - but how far the analogy can be pressed is still a matter for dispute. And one of the more disputed sectors of the field is that ofmemory, which is closely allied to the points now under discussion. If the brain is an ITD, and of the class where there is a channel of limited capacity somewhere in the reception system whose capacity is exceeded by the sort of tasks such as those we have been discussing, then merely to feed signals along alternate channels at a high rate will lead to a situation where the subject must switch.

Furthermore, to quote Broadbent (for his second assumption):

> "Introspectively, the answer was simple. One does indeed listen to only one channel at a time, and so to only one call sign: but if that call sign appears irrelevant one can change channels and still hear the relevant call-sign and message on the other channel. There seemed to be a kind of "double-take"; the sounds one had previously ignored now struck home to consciousness. The experience is a familiar one, and has been described by Hebb.... But it is one which different people describe in different words, and we have already said that it is unwise to rely on verbal accounts of the way in which responses are organised. An attempt was therefore made to establish various objective measures of this type of performance".
>
> (Broadbent, 1958, pp. 211)

Now Broadbent in speaking of "introspectively" did not mean that this was what subjects introspected themselves as doing, but that if one sat down and thought about it this seemed to be a reasonable account (Broadbent, 1959, personal communication). But even if he is right the experimental designs used do not guarantee logically that a subject must be doing this sort of switching. An analogy will make this clear. If you are observing a house and wish to see from which of two doors someone comes, there are two or three strategies open to you.

A. Fixate the lefthand door, and watch all the people who come out. If out of the corner of your eye you seem someone come out of the other door, switch your gaze. In this case the limits on the accuracy with which you can give a correct list of people who emerged will be set by the rate at which you switch, and the reliability of "the corner of your eye".

B. Switch your gaze rapidly backwards and forwards between the two doors, fixating each momentarily. The limits on your performance are here set by the rate of switching alone.

C. Fixate a point midway between the two doors, and rely upon peripheral vision to identify people coming from either door without changing your fixation point. Here the limits on your performance are set solely by the accuracy of peripheral vision, not by switching.

The important thing to notice about this situation is that simply on the basis of sending people out of the doors at different rates you cannot decide between them.

Translating, still rather picturesquely, to the auditory modality, the question can be put thus: in a dichotic listening situation, do we rush backwards and forwards between our ears, or can we sit in the middle of our heads and listen to both, at least sometimes? If the second answer is accepted, then the current attempts to measure switching time are all of faulty design, and indeed it becomes rather difficult to think of a design other than a physiological one, by which the problem can be experimentally tested. There are in fact at least two experiments which suggest that on some occasions we do listen to both ears at once, at least where very simple experiments are concerned. Firstly there is that of Ingham, (1957: see p.150 [illegible]), on doing psychophsyical judgements when paying attention to or away from the ear receiving the stimulus. Again, the following experiment is relevant.

EXPERIMENT (13)

Reaction times to pips which may be randomly presented to one of the two ears, or simply binaurally with vocal response

Method

Arising out of a suggestion by Broadbent (1958, personal communication), pips were presented through headphones to a subject, who had to make a response by saying "Up!" or "Ugh!" when he heard them. This response was used because the experiment was part of a series on audio-verbal reaction times, and the apparatus and practised subjects were available. (For information about the rest of the experiment see Davis, Taylor & Moray, 1960). Two conditions were used. In one the pips always came through both ears, and the subject knew this.

In the second condition the pips came in random order either to the left or the right ear. The assumption was that the average reaction time in the second condition should be longer, as sometimes the subject would be on the "wrong" ear when the pips came, and would have to switch.

Results

The results are given in Table (XVII).

Table (XVII)

Subject	Binaural pips		Random monaural pips		
N.M.	132	2.8	147	3.8	
A.T.	150	5.5	137	2.2	
R.D.	157	1.1	157	5.2	
	mean	s.e.	mean	s.e.	msecs.

Discussion

It is clear from these results that the prediction has not been fulfilled. There is no evidence that the randomness of the monaural presentation "catches out" the subject. And this is perhaps not surprising. Certainly, if the subject can treat the monaural condition as a binaural one and simply listen to both ears, this will be his best strategy.

Now it could be argued that if Broadbent is using a situation where interference between signals is masking any effect of switching, then in the writer's experiment (Experiment (12), above), he is doing the opposite, that is using a situation where the subject can in fact listen to both ears at once, since the signals do <u>not</u> overlap. This seems a not unreasonable conclusion. In the two cases,

Broadbent's and the writer's, the subjects are dealing with very different stimulus situations by adopting very different strategies. And here for the moment it seems that we must leave the topic.

In summary, the present writer would hold that none of the experiments done in two channel listening have estimated switching time for certain. The only way that the counter assertion can be maintained is by implicitly adopting a model of how the system is working: the experimental designs in themselves are all deficient.

Perhaps, however, we may safely say this: that certainly switching is fairly rapid if it occurs. Despite the disagreements of the author and Broadbent on matters of interpretation, both would agree in saying that switching time, for a complete cycle of ear to ear and back does not take more than about 1/3 - ½ second, and may be much less. If so, why in the basic shadowing situation, as described in Chapter II of this thesis, is the subject not able to alternate between the channels more than he does?

It will be recalled that in the previous chapter we remarked upon the case where a subject received staggered digits in a shadowing, not a listening, situation, and did not hear any of the "rejected ear" digits although the rate of presentation was certainly much lower than in the studies described in this chapter. And in the original experiment described in Chapter II the only time when a subject actually reported words from the opposite ear appeared to be when there was a very long pause for breath in the accepted message. The overall impression of the shadowing situation is that it makes the subject incapable, usually, of switching from one message to the other even

when the rate at which he is receiving the signals is such that one would not expect any particular difficulty. With this idea in mind, the following experiment was designed to compare with the original experiment (Experiment (1)), in Chapter II.

EXPERIMENT (14)

A comparison of performance during a) shadowing, and b) listening to one of two dichotic messages

Method

The method used was similar to that in Experiment (1), except that subjects were not to shadow, but merely to listen to the indicated message. They were told that they would hear one message in their right ear, and another, different message in their left ear. They were to listen to one ear and ignore the other. At the end of the message they would be asked questions about the message which they had listened to.

The same passage was used as in Experiment (1), but only the first hundred words were given. The subjects were given four practise passages of about 100 words before the test run started. 6 subjects were used, undergraduates, naive to the experimental situation.

Results and Discussion

Of the 6 subjects, five of them reported one or more words from the rejected message, and remarked that they had not been able to keep their attention on the message which they had meant to. The only subject who did not report any words nonetheless knew that the rejected

message was composed of short words, and on closer inspection it was found that owing to an oversight he had received a rejected message which was 8 db quieter than the accepted message. In short the picture is very different from the shadowing case, where subjects had shadowed the same message for several minutes, and although the rejected message had been repeated 35 times could remember nothing from it. It would seem that the act of shadowing does indeed convey an enormous advantage over mere listening in such a situation.

Something about shadowing as it were "smoothes over" discontinuities in the accepted message, and it would seem that here is the reason why subjects do not switch in situations where we might well expect them to. One has the impression of a system which in the act of shadowing aquires a certain "momentum" which carries it over gaps in the message, rather as a skier moving at speed can jump a crevasse, whereas if he were just walking he would not be able to get across. At present it is not possible in detail to say what is going on in the organism, although a rough account was given in Chapter III, where, it will be recalled, a general theory of selective listening was put forward in terms of correlation, prediction, and transitional probabilities. We suggested that the outcome of any selective situation was the result of the interplay of a bias introduced by the subject's decision to admit one message and reject another, together with the effects of certain characteristics of the messages themselves. A good example of such an interaction is provided by an experiment by Taylor (Taylor, Anne, 1959, personal communication). She had her subjects shadow a message with a different one on the opposite ear, and

then swapped each message to the opposite ear in the middle of the passage. The subjects continued shadowing the message which they had been shadowing for a few words and then went back to the ear which they had selected at the beginning of the experiment, usually being unaware of their momentary "defection" to the wrong message. Here we see that the "momentum" of the shadowing response overrides for a short time the "bias" which the selective act of the subject introduces: it will be seen that in terms of the "feedback prediction" and correlation model suggested in Chapter III this sort of situation is just what we would expect.

This brings to an end the consideration of switching of attention in dichotic listening. We may conclude that while there is some evidence as to why switching is so well resisted in a shadowing situation, we are very far from being able to be sure about how long switching takes. That there is literally "switching" from ear to ear on many occasions seems beyond doubt whatever rival interpretations we may put on the digit listening experiments of Broadbent and the writer:there are cases like the study of the response to affective stimuli reported in Chapter IV which certainly indicate that something of the sort occurs, and neurologically it is very credible, although as we shall see later the picture is not very clear even there. The situation is one rather more attractive to the worker in search of problems at the moment than for him who requires results and conclusions.

CHAPTER VI

The Nature of "Attention" in Selective Listening

"Quid est ergo tempus? Si nemo ex me quaerat scio; si quaerenti explicare velim, nescio."

Augustine, The Confessions.

"Everyone knowswhat attention is."

William James, Principles of Psychology.

"We see a complicated network of similarities overlapping and criss-crossing: sometimes overall similarities, sometimes similarities of detail. . . . . I can think of no better expression to characterise these resemblances than "family resemblances"."

Wittgenstein, Investigations.

Despite the optimistic remark of James, quoted above, the present writer is more inclined to side with Augustine, substituting the word "attention" for time. Certainly there is much in common among the various uses of attention, but nonetheless there are also many differences, some obvious, some more subtle. Indeed, for almost every definition which has been offered it is possible to find an exception in the experimental literature.

There seem to be at least seven or eight clearly distinct ways in which attention has been used in the literature.

The first of these makes attention almost synonymous with consciousness, at least in the sense that "paying attention to", and "being conscious of" are used almost interchangeably. For

example, the quotation of James given at the start of this chapter continues,

> "It is the taking possession by the mind, in clear and vivid form, of one out of what seems simultaneously possible objects or trains of thought. Focalisation, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatter-brained state which in French is called 'distraction' and 'Zerstreutheit' in German."
>
> (William James, op.cit.)

Here James is clearly regarding attention as a state of mind, rather than a process, although at first sight it seems to bear a resemblance to our use of "attention" in that it contrasts attention with the distracted state. But it is fairly clear on inspection that all that James is doing here is to re-describe the phenomena which he is examining, and that he does not in fact throw very much light on the problem. He does not suggest a mechanism, or at least, if he does, it is what Hebb has described as

> " . . . various properties of "mind", undefinable and impossible to understand."
>
> (Hebb, Organisation of Behaviour, 1948)

What James's account does draw attention to is the element of selection, which is almost universally present in definitions of attention, although even this is almost lacking in the case of "vigilance", and Wittenborn's factor, as we shall see below. That James's use of the term is not the same as ours is clearly brought out in a quotation from later on in his chapters on attention:

> "There is no such thing as voluntary attention sustained for more than a few seconds at a time. What is called

> voluntary attention is a repetition of successive efforts which bring back the topic to the mind."
>
> (William James, op.cit.)

Clearly this is a far cry from the shadowing condition in Experiment (1), where the subject maintained voluntarily directed attention to the selected message for minutes, rather than seconds, on end. The performance of shadowing, it becomes clear, introduces a situation and a use of "attention" which is not found anywhere in the scope of James's investigation.

To dispose very quickly of another classical, but now discontinued use of the term "attention", let us recall its application to the experiments of Hamilton, Jevons, etc., on the maximum number of individual stimuli which can be perceived in a short visual exposure. Initially these experiments were call "span of attention", and were intended to throw light on the problem of how many things the mind can do at once, but here the use rapidly fell out of favour, and was replaced by the term "span of apprehension", and conceptually the experiments came to be regarded rather as problems of perception than of attention. It is worth remarking, however, that the current interest in communication theory models of the organism seems likely, in the context of such theories as Broadbent's Filter Theory (Broadbent, 1958), to reinstate this problem as one of attention, where the latter is related to a mechanism of limited channel capacity being bombarded with a multi-channel input. However, whatever its status, it is rather far from our use of the term "attention" as synonymous for "listening selectively".

Another writer to use "attention" in a mentalistic sense was William McDougall. In his "Outline of Psychology", (McDougall, 1928),

he says,

> "Attention is merely conation or striving considered from the point of view of its effect upon the cognitive processes."

which would no doubt call forth anew the somewhat acid remark of Hebb which we have already noted. Here again, not merely is the use not very close to that in which we are interested, but is again a redescription, not a model. The use is related to the term "set", at least in a loose way, and also to James's "capturing" of consciousness by stimuli.

Titchener, (1903), in his book "The Psychology of Feeling and Attention", provides a more tangible approach to the problem. He gives a list of the qualities determining which stimuli will "capture" the attention. The list consists of the following items: intensity, extension, duration, certain qualitative characteristics, repetition and suddenness, movement, novelty, association with ideas already present, accommodation of sense organs, and the cessation of the stimulus. And a comparison of the importance of these in traditional attention tasks and in speech shadowing throws up some interesting differences.

Intensity: we have seen that unlike many classical experimental investigations those on speech shadowing show very little effect on performance when there are quite large disparities of intensity which would be expected to affect seriously the performance. The clue to this is partly to be seen in the work of Egan et al., (see p. 29 above), which showed that the organisation of the auditory system is such that dichotic presentation of stimuli prevents intensity disparities from being effective.

Extension and duration: these are used by Titchener rather in the same way as intensity - he seems to be thinking of some sort of stimulus summation as giving to the stimulus a better chance of capturing the attention. Perhaps the nearest relevant data in these experiments on speech shadowing comes from Experiment (1). Here the constant repetition of the stimuli might be regarded as an increase in their extension and duration. If the analogy is valid, then clearly we are dealing here with a very different mechanism from that which Titchener has in mind.

Certain qualitative characteristics: which he goes on to describe as,

". . . intimate, worrying, wicked things . . . "

(see p. 81 above).

Here we come to a point of agreement, for it will be remembered that at least two experiments, that using the subjects' names, and that using a conditioned GSR response, found evidence that material of this kind could indeed capture the attention even in a dichotic shadowing situation. This role of affectively toned stimuli, "important" stimuli, in the capturing of the attention seems to be one of the few universally applicable findings in attention studies.

Repetition and suddenness: we have already seen that repetition is singularly ineffective in giving a stimulus attention-catching value in these situations (Experiment (1), and above, "Duration and Extension"). Suddenness however does seem to be another of the "universals" of attention. Broadbent (1953) has emphasised the importance of "new" stimuli, and has indeed (1958) suggested that if one input channel of the organism is used for any length of time the other channels become

increasingly likely to "capture" the filter and with it the pathways into the limited capacity parts of the system. Also in Cherry's (1953) experiments the sort of things which the subjects noticed while they were shadowing were often the points at which the message changed in quality, or began or ended. A sudden change, even of quite small magnitude does seem to be a very strong stimulus for catching the attention; the organism is very "change sensitive".

Movement: in the sense of a melody moving against a background. Here Taylor's (1960) work is relevant. She found that interference with shadowing was less if there were two messages going to the rejected ear than if there were one, and in general this agrees with the remarks of Egan et al. about the relative efficiencies of noise and speech as a distracting stimulus. Note also that in shadowing, as in listening, it is the initial identification of the message which is the difficult task; once the subject "gets hold of" the message he can perform the task well. This again appears to be a fairly universal "law of attention".

Novelty: as we saw above under the heading of "suddenness" there are certain changes which are noticed in the rejected message in dichotic shadowing, and indeed "change" as such seems often noticed even when nothing else is. In this sense, novelty is a good captor of the attention in most cases. However, it should be born in mind that in Cherry's (1953) study by no menas all the changes were noticed. For example, the subject did not notice if the speech was changed from one language to another in the rejected ear. Changes which involve certain sorts of "high level" analysis by the brain are not effective in breaking down the attentional block.

Association with ideas already present: in the sense, in Titchener's use, of affective associations. Affective stimuli themselves are of course able to "capture" the attention, and if the results of the GSR conditioning experiment are accepted as positive, then words with affective associations can also act in this way. But we might take the idea of association in a different way, namely that association between stimuli introduces redundancy into a stimulus situation. We saw (p. 61) that a highly redundant message is easier subjectively for the subject to shadow, and also that he makes more errors in a non-redundant task, although even when the rejected message is highly redundant with respect to the accepted message, it does not break through the subject's selective barrier set up in dichotic shadowing.

Accommodation of sense organs: this is very much less important in hearing than in vision as a matter of course. For whereas in vision part of the reaction to a visual stimulus consists in focussing, accommodation, etc., in hearing there is much less variation of the state of the sense organ as a whole in response to varying stimuli. Indeed almost the only important changes of this kind is the response of the Tensor Tympani muscle and the other structures of the middle ear, which are not under voluntary control as are the focussin and convergence mechanisms of the eye. Some of the work by Galambos (1955), and Hernadez-Peon et al. (1957) seem to suggest that there could be changes in the state of the cochlea or the very low-level synapses of the auditory pathway, and these would, if found to play a great part in the selective acts of dichotic shadowing, be included under this heading of Titchener's.

But evidence will be presented in the next chapter to indicate that the blocks which occur in this kind of selective listening must be at a much higher level in the brain than the periphery. Moreover the experiment by Ingham (1957) suggests that the direction of the attention has very little effect on altering the simple threshold mechanisms for pitch and intensity, whereas if there were marked changes in the "accommodation" (in Titchener's sense) of the sense organs, one would have expected a marked difference between Ingham's two groups of data (see p. 150).

Cessation of stimulus: this is of course a special case of "change", or "novelty", and as such would be expected to break down the attention. It is true that the ending of a message was noticed by subjects in Cherry's (1953) experiment, and that subjects in Experiment (1) were able to distinguish between prose and lists of words, and that this agrees with Titchener's dictum. But it raises another point, one which was discussed in Chapter III. Are these cases of the "attention" being "captured", or are there two mechanisms, one concerned with pattern analysis, where the left or right ear pathways can be operated on selectively by the brain, and another, concerned with the treatment of what has been called above the "raw data", in which selection does not occur in the sense of being able to "turn off" one ear or the other.

Looking back over this list of the qualities of attention-catching stimulus with which Titchener has presented us, it is clear that at least some of them are shared by "attention" as seen in dichotic selective shadowing. But at the same time one has a feeling that the relation is <u>not more</u> than a "family resemblance", to quote Wittgenstein.

Particularly with regard to the thoroughness with which the subject is able to avoid distraction by shadowing one has the feeling that Cherry has unearthed what is a rather extraordinary kind of attention.

It is clear that we do not want to relate it to attention as "sensible clearness", (the phrase which Titchener uses to describe the doctrine of Apperception as put forward by Wundt), for the phenomena to which this refers are logically private experiences. The idea that by paying attention to a stimulus we make it subjectively more clear is one that is difficult to tie down with public criteria, and associated as this doctrine is with the Introspectionist school of psychology, it is not intended to be a use which can be attacked by the experimental psychologist of today. In this connexion it is interesting to look at Ingham's experiment again. In the classical work, the subject would have been asked if by paying attention or not to a stimulus made it subjectively more clear. And as the whole of the work of Wundt and Titchener indicates, he would have undoubtedly said that when he paid attention to one stimulus the other became less clear: indeed one has a vague suspicion of a lurking tautology in the concept as used by these writers, one so heavily disguised that it even resisted the experimental efforts aimed at its discovery. On the other hand, Ingham, using an objective psychophysical method with no reference to the subjects' experiences of any "clearness", showed that the direction of attention in such tasks apparently made no difference. The whole raison d'etre of this thesis is to show examples of the objective measurement of attention, and as such almost by definition - in the adoption of an operational conceptual definition - we have excluded

such an approach as that of Wundt.

Turning to a modern use of the concept of attention, we come to the experiments on Vigilance.

These would certainly be described colloquially as experiments on attention, and Broadbent makes their discussion the occasion to give a defence of his resurrecting the topic of attention from its recent obscurity:

> "But above all attention is a topic which has lately been neglected but which was of great weight in textbooks of an earlier time . . . It fell into bad odour because of the inability of introspective psychologists to agree with one another, or to provide objective evidence to back their assertions . . . . the vigilance experiments have forced us to acknowledge again the importance of attention, which the theories of the past 30 years have not mentioned."
>
> (Broadbent, 1958, p.109).

But again this use of the term seems very far from the sort of use which we are making of it. If we boroow the terminology of communication theory, vigilance experiments are more concerned with the problem of the detection of signals in noise than with the mechanisms which regulate the admission of signals into the system through a number of competitive channels. Broadbent, however, relates the two by saying,

> "We have come to the conclusion that after prolonged observation of one source of information, a man will show brief intervals in which he takes in information from other sources."
>
> (Broadbent, op. cit. p. 108).

The differences in the sort of tasks in the two sorts of experiments are enormous. The typical vigilance experiment is one of impoverished stimulation, which can hardly be said for the shadowing task, and the subjects in shadowing are continually engaged in giving responses,

unlike vigilance tasks. It is known that the decline in performance which is observed in vigilance tasks with occasional stimuli does not occur when the subjects have continually to make responses, and so we would not expect to find the same sort of phenomena in the two cases. Related results are those of Bakan (1952), and Kappauf et al. (1955).

Bakan investigated a vigilance situation in which his subjects were required to listen to lists of digits during a 90 minute period on successive days, and to write on cards any three-successive-odd-digit sequences that they heard. The results showed that with only this amount of responses to make, which is rather less than, e.g., the Cambridge cockpit tests (Davis, 1948) required, the now classical curve of falling performance over a period of an hour was found. This task would seem to be about half way, in terms of the amount of stimulation and response involved, between the radar watching experiments of

and the shadowing experiments. The complete comparison is not possible, since to date no shadowing experiment has been carried on for the length of time which is needed to show the classical vigilance deterioration of performance.

A word which is closely related in its use to attention is "set". There is little doubt that by combing through the many uses of this word we could find some which were similar to the sort of thing for which we are looking here. But while "set" began its life as an explanatory concept, it has by and large spread in rather an emorphous way until its current use is so vague as to be of very little help. Gibson indeed suggested that it might be dropped from psychological

use all together with very little loss, and provided a list of over a dozen different ways in which the term had at some time been used (Gibson, 1941). Hebb has said,

> "When an experimental result makes it necessary to refer to 'set' or 'attention' the references means, precisely, that the activity that controls the form, speed, strength or duration of the response is not the immediately preceding excitation of the receptor cells alone."
>
> (Hebb, 1949)

which while being true to some extent is not particularly illuminating if we are looking for the mechanisms involved. In general "set" seems to have come to refer to the subjects' attitudes to the task rather than to any mechanisms involved, as did the concept of the "aufgabe", as used, e.g. by Chapman (1932).

It is clear that the greatest similarities between the use of "attention" in dichotic shadowing experiments and its use in other experiments will be found in conditions which have this in common: that, as was said above (p. 151), the situation is one of selecting between channels of input which can be used mutually exclusively at different times, or combined in some situations. At first sight the experiments most similar to those described in this thesis are those on binocular rivalry. But there are differences: to begin with the choice of channels is not under the subject's control to nearly the extent in vision that it is in hearing. It is generally accepted that whatever subjects may claim, there are very few of them who can actually choose which eye they will look with at will. (It is however interesting that Taylor has recently found similarities between reading stereoscopically combined messages and shadowing dichotic messages. (Taylor, 1958, personal communication)).

Also the present writer has a certain disinclination to argue from the organisation of one sense modality to that of another - especially when one of them is vision, where the nature of the stimulus is unlike that of any of the other senses, and the interactions between the two sense organs suggest that the organisation is definitely very different from that in hearing. (Anatomically this is shown at a very naive level by the fact that there is no "auditory chiasma".)

What can we gather from this rather negative survey? Probably that we are not investigating, in dichotic shadowing, a behaviour which has much in common with any others. It would be a great help if some attempt, prefigured by this brief review, were made to sort out the various uses of "attention" not merely on the basis of a review, but actually experimentally. That such an attempt might be fruitful is indicated by the following experiment.

EXPERIMENT (15)

A study of performance on Wittenborn's tests of attention and in a dichotic shadowing situation

Wittenborn (1943) undertook a factorial analysis of several tests of attention. He examined twenty tests, some old and some specifically related to sustained mental effort. Practice effect, rote memory, space factors, etc., were all analysed out. Two of the tests were particularly heavily loaded with such a factor. The design of the tests is best shown by quoting Wittenborn's original instructions:

> "Test 11.
>
> You will hear sets of three digits. Some of the digits will require no response. Some will be responded to by marking a plus in the answer space. This will be on one of two conditions. (1) When the first number is

the largest and the second the smallest. (2) When the third number is the largest and the first the smallest."

"Test 17.
Lists of letters selected from the alphabet will be read. You will respond to some of the letters by marking a plus. You will respond to others by marking a minus. Others will require no response . . . . . Mark a vowel following a consonant +, a consonant following a vowel - , and when two vowels or consonants occur together, mark the next letter + no matter what it is."

The first test was presented at a rate of 96 digits per minute with a pause equivalent in length to one digit between each groups of three digits. Twelve groups of three digits were given in a run, and a one second pause was given between each run. In the second test the letters were presented at a rate of 66 per minute, with a pause equal to four letters between each run of fourteen letters. Ten runs of numbers were given in the first test and ten runs of letters in the second. The lists were prepared using random number tables, and were pre-recorded, together with the instructions, on magnetic tape, so that standard instructions and standard methods of presentation were used for all subjects. The subjects were given a proforma with spaces to make the relevant marks, and with a description of the procedure on the top. They were allowed to study this for five minutes until they were sure that they understood what theyhad to do. They were then given two sample lists correctly filled in to do while listening to the tape recording of stimuli, and then three practices runs in the first test and four in the second. The number of errors was scored against a key which had been prepared and double checked in advance.

For comparison, the scores obtained by the same subjects in the experiments on shadowing statistical approximations to English

Test I

name . . . . . .

You will hear sets of three digits. Some of the sets will require no response. Some of the sets of digits will require you to respond by marking a plus (+) in the appropriate space.

You will mark the set plus under two conditions:

1. when the <u>first</u> number is the largest of the three and the <u>second</u> number is the smallest of the three.
2. when the <u>third</u> number of the three is the largest and the <u>first</u> number is the smallest of the three.

otherwise do not make any mark at all.

Below are shown two sample series with the correct answers.

There are also three spaces for practice series. The numbers will be presented over the loudspeaker. The first of the practice series has been filled in correctly so that you can check your results as you go through it.

Sample Series A	a	Sample Series B	b	Practice C	D	E
1 3 4	+	4 1 3	+	+		
2 7 5		7 3 8				
3 8 9	+	9 3 7	+			
9 6 8	+	7 5 2		+		
8 6 2		9 3 2				
4 1 8		2 7 4				
5 3 4	+	3 5 9	+	+		
7 2 6	+	9 5 4				
5 4 8		8 9 7		+		
8 5 3		3 8 2		+		
7 9 5		6 5 7		+		
4 7 3		7 4 9		+		

Now turn to the second page for the score sheet for the test proper.

HAVE YOU WRITTEN YOUR NAME AT THE TOP OF THIS PAGE ?

Test Score Sheet.

List 1	List2	List 3	List 4	List 5	List 6	List 7	List 8	List 9	List 10

Test II

Name . . . . . .

Instructions.

Liats of letters selected from the alphabet will be read. You will respond to some of the letters by marking a plus (+). You will respond to other letters by marking a minus (-). Some of the letters will require no response.

This answer sheet has been prepared for recording your responses.

The spaces below are arranged in lists. The lists below correspond by number to the lists that will be read out to you over the loudspeaker. The letters within each list are numbered, and these numbers correspond to the answer space reserved for that letter.

This is how you are to mark the answer spaces:

1. Mark a vowel following a consonant plus (+).
2. Mark a consonant following a vowel minus (-).
3. If two vowels or two consonants occur together, that is a vowel followed by a vowel or a consonant followed by a consonant, mark the next letter plus (+) no matter what it is.

The samples are correctly answered.

Four practice passages will be read to you so that you can get used to the proceedure. The first of these has been filled in so that you can follow as you answer (Practice list 1).

Sample List X	List x	Sample List Y	List y	Practice: - List 1	List 2	List 3	List 4
1-A	1	1-X	1	1	1	1	1
2-D	2 -	2-L	2	2	2	2	2
3-C	3	3-O	3 +	3 +	3	3	3
4-D	4 +	4-P	4 -	4 +	4	4	4
5-A	5 +	5-R	5	5 +	5	5	5
6-O	6	6-U	6 +	6 -	6	6	6
7-L	7 +	7-F	7 -	7	7	7	7
8-M	8	8-C	8	8 +	8	8	8
9-N	9 +	9-J	9 +	9 -	9	9	9
10-R	10 +	10-N	10 +	10	10	10	10
11-U	11 +	11-E	11 +	11 +	11	11	11
12-V	12 -	12-G	12 -	12 -	12	12	12
13-S	13	13-G	13	13	13	13	13
14-U	14 +	14 D	14 +	14 +	14	14	14

Now turn over to the second sheet where the score spaces for the test proper will be found.

HAVE YOU WRITTEN YOUR NAME AT THE TOP OF THIS SHEET ?

Test Lists

List 1	List 2	List 3	List 4	List 5	List 6	List 7	List 8	List 9	List 10
1	1	1	1	1 1	1	1	1	1	1
2	2	2 2		2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9	9	9
10	10	10	10	10	10	10	10	10	10
11	11	11	11	11	11	11	11	11	11
12	12	12	12	12	12	12	12	12	12
13	13	13	13	13	13	13	13	13	13
14	14	14	14	14	14	14	14	14	14

(see above, p. 63) were used. The geometric mean for each subject was calculated for the Omissions data, (since the curve was an exponential), and the arithmetic mean for the mistakes, (since this was a straight line).

Correlations were performed between each test and the omissions scores, each test and the mistakes scores, and between the omissions and mistakes, and between the two tests.

Samples of the tests are given on ~~Figures XV and XVI~~ pp. 156 & 158

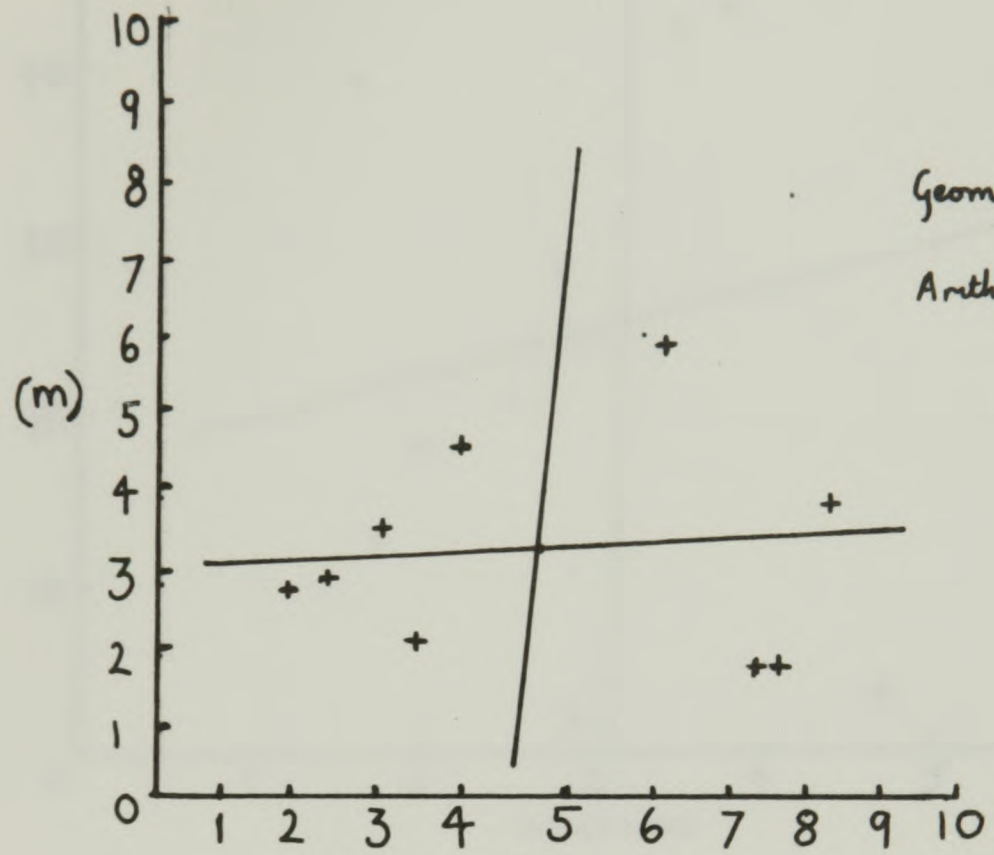
The raw data is given in Table XVIII.

The correlation calculations' results are given in Table XIX, and Figure XVIII.

Results

It will be seen from the results that there are clearly great differences between the performances of a subject on the Wittenborn tests and in the shadowing situation. The correlation between an individual's scores on the two Wittenborn tests is quite high, which at least bears witness to the skill with which Wittenborn carried out his original investigation. But the only other correlation which is of any size is that between Omissions score and the performance on Wittenborn's Digit test which even so is not significant at $p = 0.05$. The correlation between omissions and mistakes is very low, which bears out the suggestion that was made earlier that they are due to two different mechanisms. The letter test in particular shows extremely low correlations with either omissions or mistakes, although the Digit test does slightly better, at least for the omissions data. Bearing in

FIGURE XVI (a)



(o)

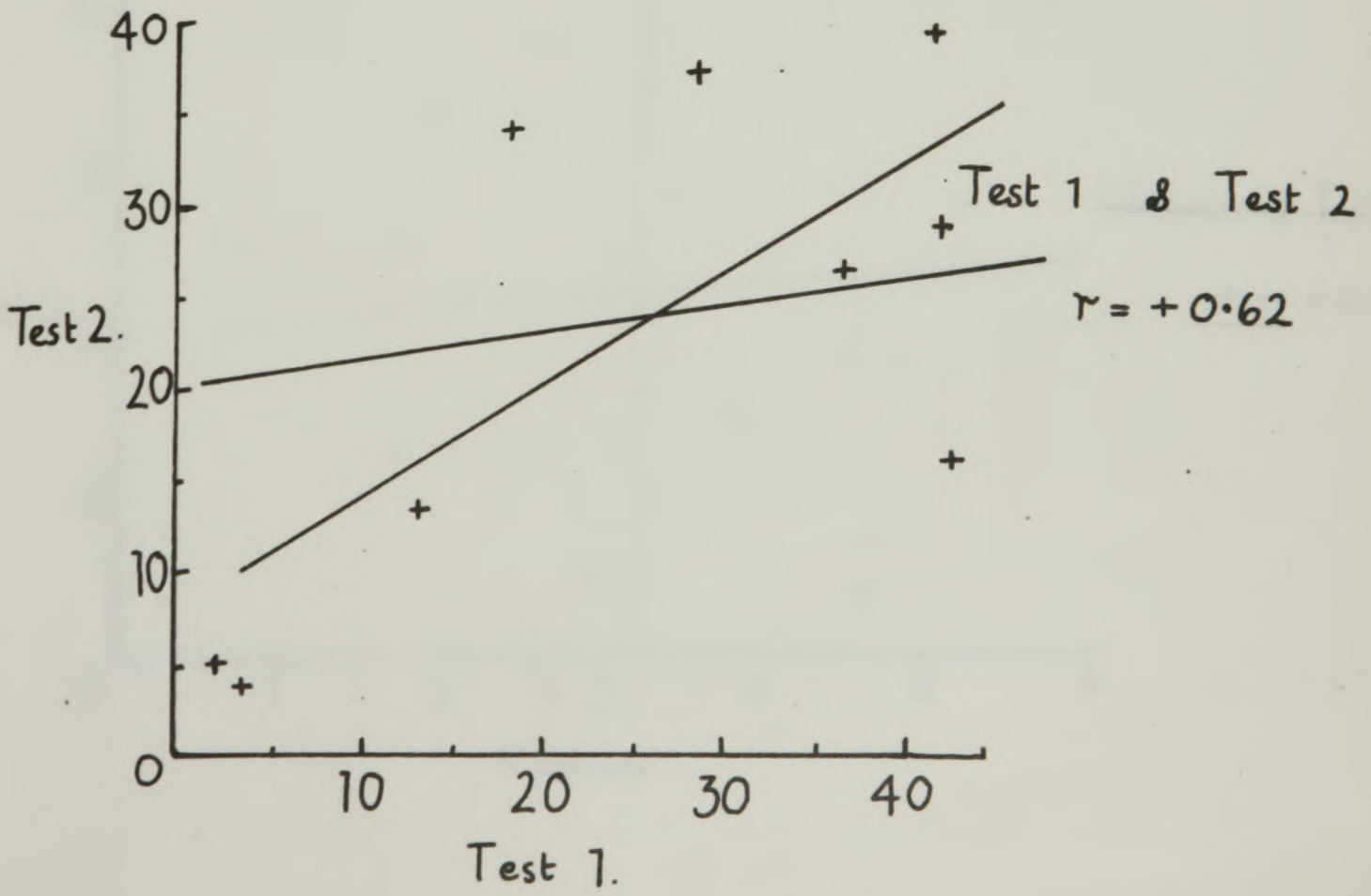
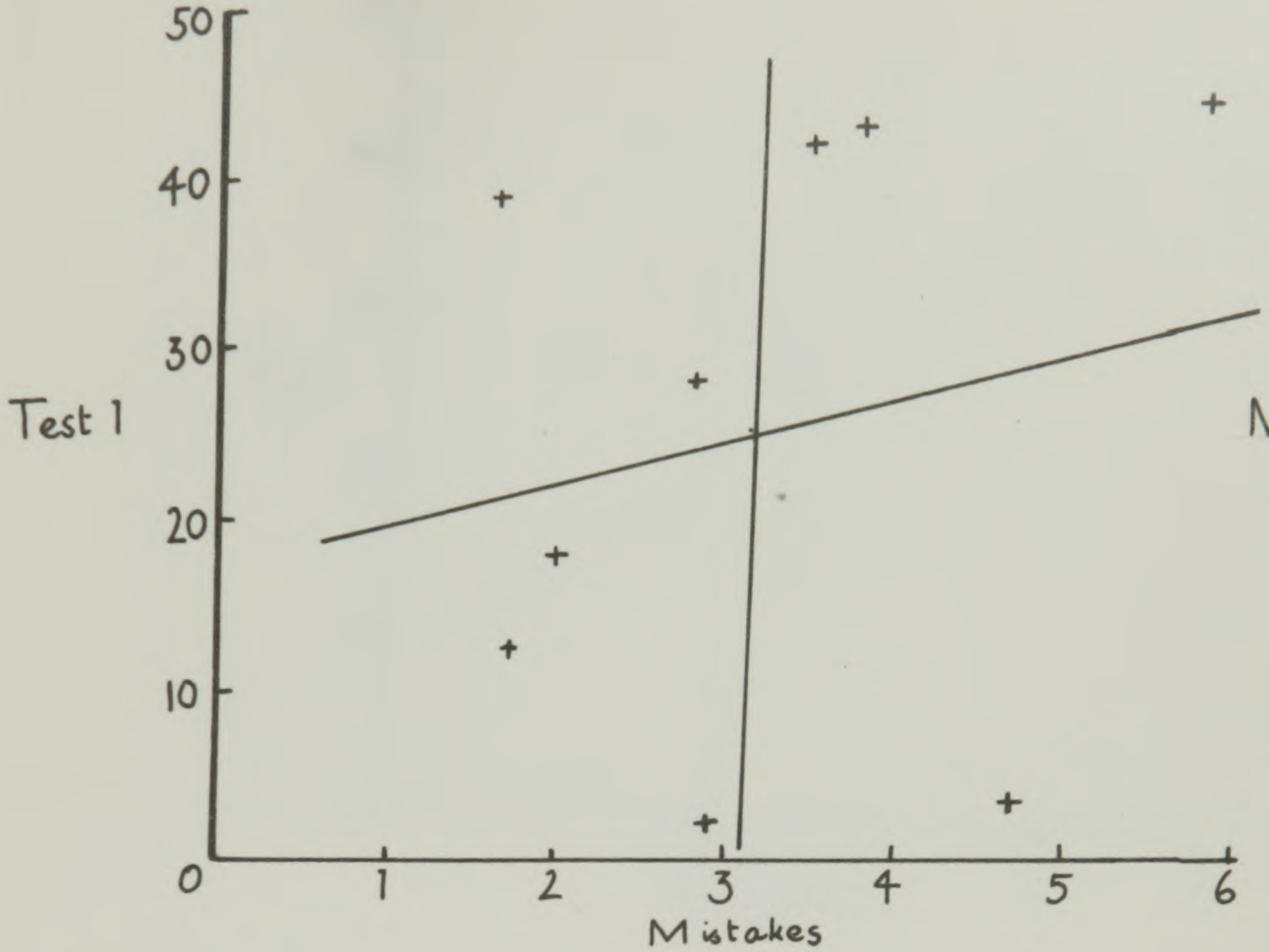
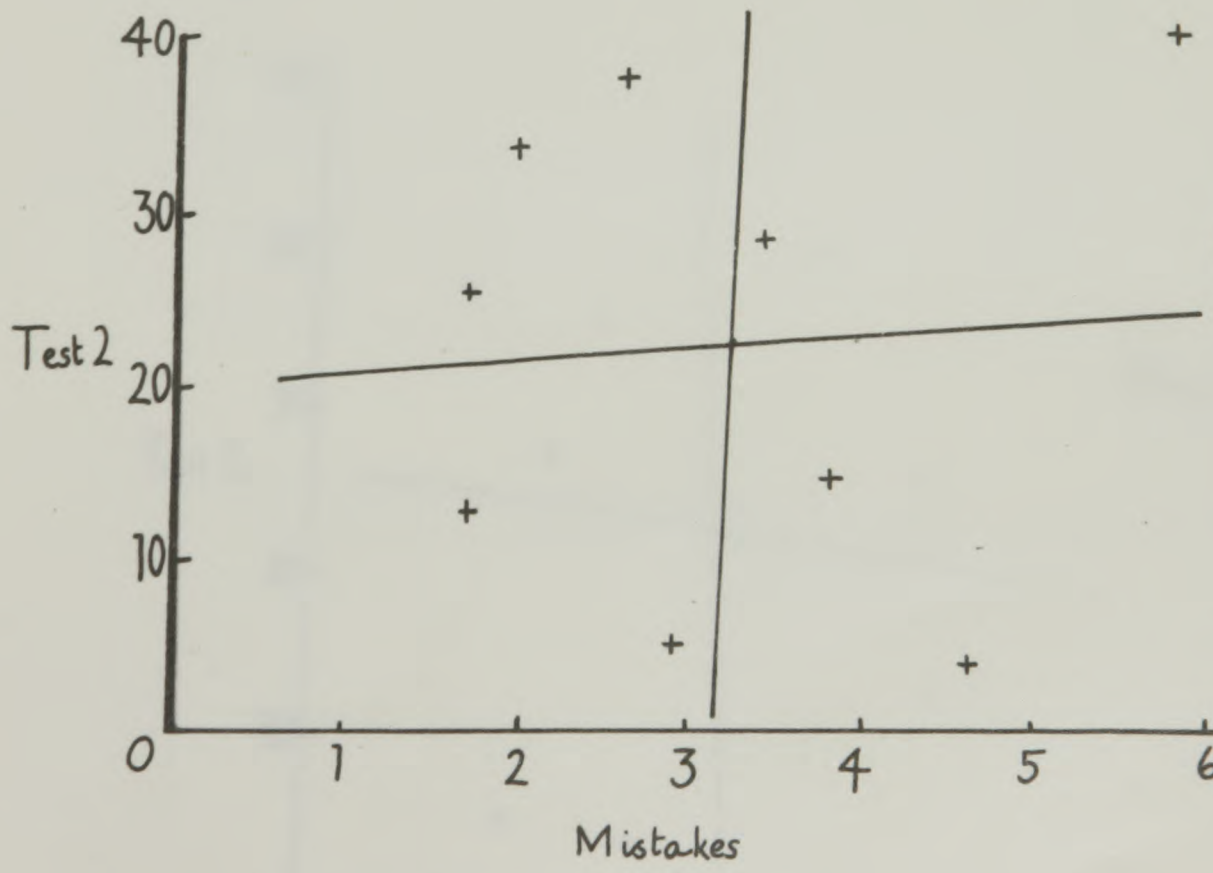


FIGURE XVI (b)



Mistakes & Test 1.

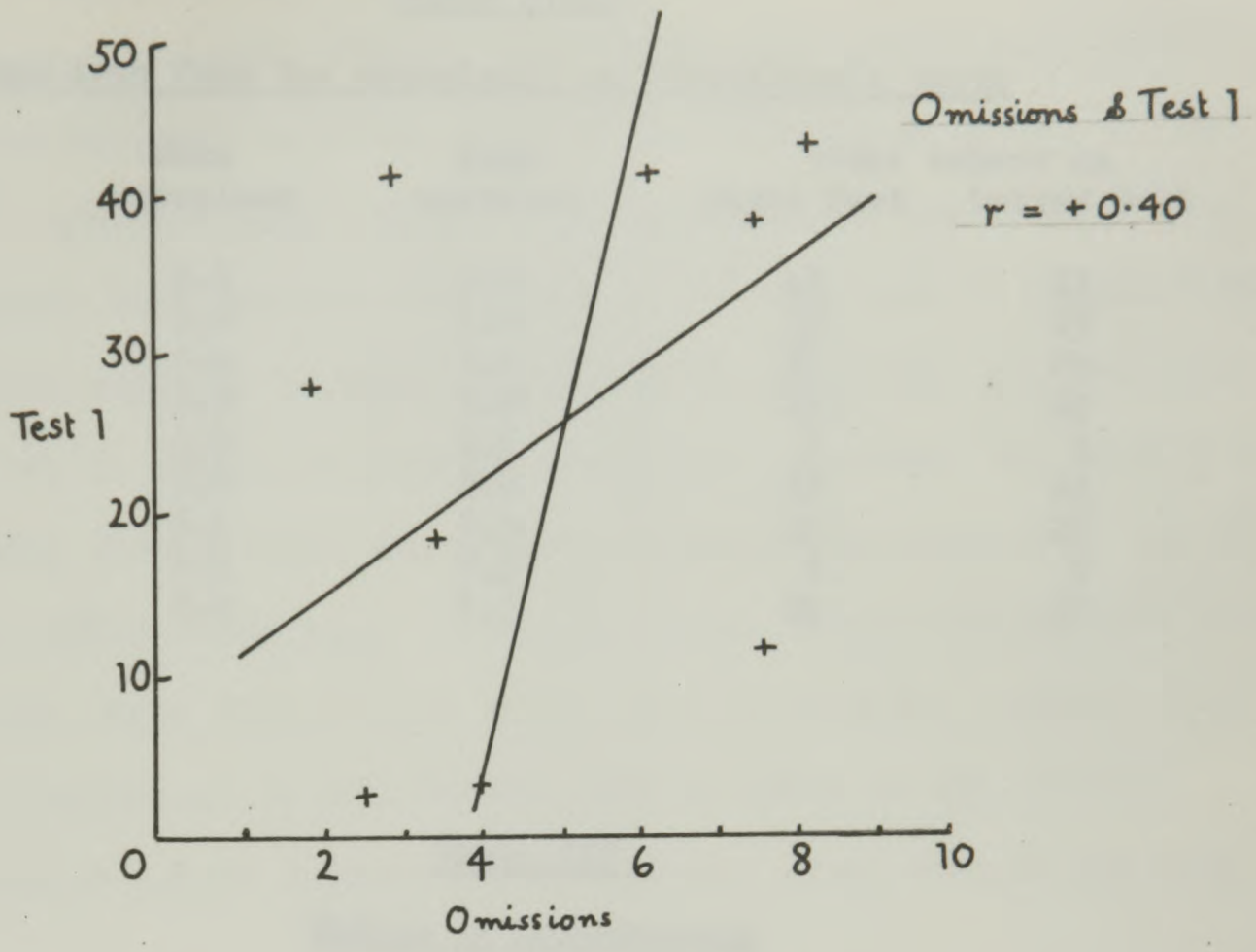
r = +0·23



Mistakes & Test 2

r = +0·07

FIGURE XVI(c)


50
40
30
20
10
0
2
4
6
8
10
Test 1
Omissions
Omissions & Test 1
r = +0·40

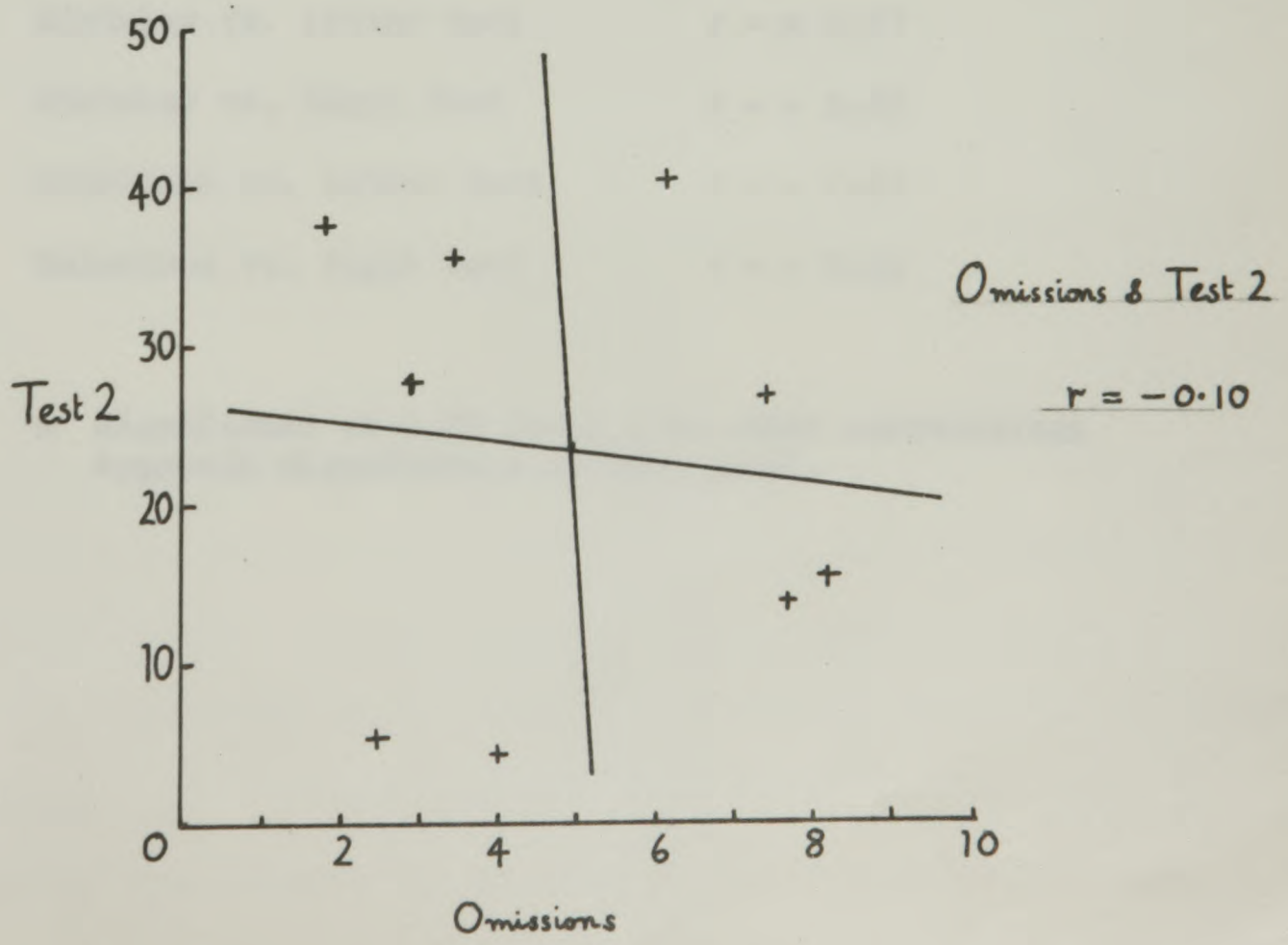

50
40
30
20
10
0
2
4
6
8
10
Test 2
Omissions
Omissions & Test 2
r = −0·10

Table XVIII

Raw data from the experiment on Wittenborn's tests

Subject	Mean omissions	Mean mistakes	Total errors on Digit Test	Total errors on Letter Test
J.R.	8.3	3.8	43	14
M.R.	7.6	1.8	13	13
P.E.	7.4	1.8	37	26
J.M.	6.3	5.8	41	40
J.T.	4.0	4.6	3	4
M.C.	3.6	2.0	18	34
K.C.	3.1	3.5	41	27
G.B.	2.5	2.9	2	5
C.C.	2.0	2.8	28	37

Table XIX

Tables of correlations

Omissions vs. Mistakes	$r = + 0.04$
Digit Test vs. Letter Test	$r = + 0.62^{*}$
Mistakes vs. Letter Test	$r = + 0.07$
Mistakes vs. Digit Test	$r = + 0.23$
Omissions vs. Letter Test	$r = - 0.10$
Omissions vs. Digit Test	$r = + 0.40$

* Significant at 0.05 level : no other correlations approach significance at this level.

mind the suggestion that omissions are due to central factors, and mistakes to peripheral factors, this is not very surprising, since Wittenborn expressly held his tests to be measuring attention in the sense of sustained mental effort. But the general low level of the correlations does indicate that there is not very much in common between the various measures of attention here being examined: it seems that in this way it should be possible empirically to attack the problem of determining whether there are several distinct processes which are all normally called attention. Certainly Woodworth and Schlosberg's remark (1950) made about Wittenborn's tests, that if anything deserves to be called attention it is this factor, even if taken in the somewhat light-hearted spirit in which it was offered, seems wide of the mark.

CHAPTER VII

The neurophysiology of Selective Listening

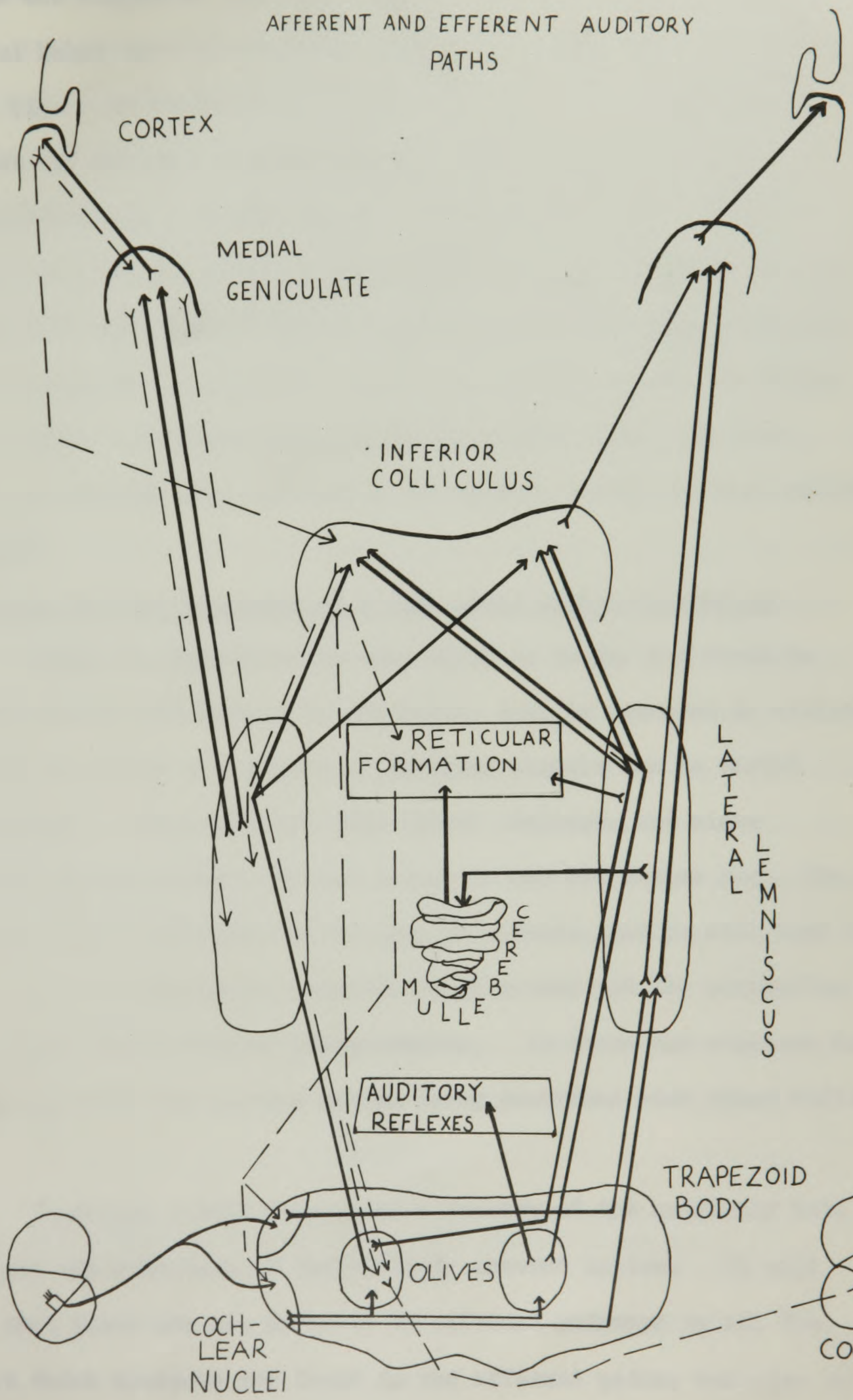
"Where is the seat of the mind,
and where is the place of understanding?
. . . . . .
It is hid from the eyes of all mortal men
And the fowls of the air know it not. "

(Book of Job)

The time has come to investigate the extent to which our current neurophysiological knowledge can confirm the suggestions that have been made throughout this thesis about the structure and organisation of the selective mechanisms in hearing. While it is not true that the "ultimate explanation" of behaviour must be given in terms of neurophysiology, it should be the case at least that psychological theories bear some relation to the known facts of physiology, since the structure of the brain underlies behaviour biologically, although physiological explanations do not logically underly psychological ones.

There are five main suggestions which have been put forward in this thesis and which we will try to link with physiological mechanisms. (1). It was suggested that there is a dual input system in hearing, one pathway of which carries input signals to the mechanisms concerned with the analysis of meaning, while the other simply treats words as "sound". It was suggested thatthe former, but not the latter, could be "turned off" selectively when listening to one ear and disregarding the other. (2). It was suggested that there are three sorts of comparison done between the messages to the two ears, and if so, we may ask at what level in the nervous system the comparators lie.

FIGURE XVII


AFFERENT AND EFFERENT AUDITORY PATHS
CORTEX
MEDIAL GENICULATE
INFERIOR COLLICULUS
RETICULAR FORMATION
LATERAL LEMNISCUS
CEREBELLUM
AUDITORY REFLEXES
TRAPEZOID BODY
OLIVES
COCH-LEAR NUCLEI
COCHLEA

(3). It was suggested that there is some pattern recognition done at a level below that of conscious awareness. Where does this take place? (4). It was suggested that there was a "blocking" of the input from one ear when the message presented to the opposite ear was being shadowed. At what level is this block? (5). It was suggested that the actual behavioural response of the subject was the result of the interplay of several factors - the "biassing" introduced into the system by the subject's decision to listen to one ear rather than the other, the output from the "comparators", etc. By what pathways and through what centres in the nervous system do these effects come about?

1. Evidence for the existence of a dual input system in hearing

Since the hypothesis is that words as words, and words as sound are treated differently by the brain, what is required is evidence that these two sorts of analysis of incoming signals can be varied independently. Since only man uses verbal language, and since experiments on the central nervous system in man are rather rare, the hypothesis will be extended to the case of animals, and we will look for evidence that the perception of patterns of sounds and the perception of simple sounds can be altered independently. Is there any evidence for different parts of the nervous system being concerned with these different tasks?

In Figure (XVII) is given a summary of the currently held ideas about the structure of the auditory nervous system. It will be seen that there are now known to be efferent pathways to all the levels at which synapses are found in the afferent paths, and also that

at each level there are interconnexions between the pathways from the left and right ears. It is known that there is interaction between inputs from the two sides at each level at which the afferent pathways have synapses (Rosensweig & Wyers, (1955), Rosensweig & Sutton, (1958)) so that there are present pathways which potentially provide mechanisms for quite complicated interactions. It is also known (Galambos, 1954) that the auditory cortex of each hemisphere receives fibres from both ears, and although estimates vary considerably in assessing the degree to which each ear is bilaterally represented at the cortex, it seems that each ear is probably equally represented on each side, plus or minus some 10%. At the cortex there now seems fairly general agreement that four areas - at least in the cat - are involved in the auditory responses: these are the two classical auditory areas AI and AII on the superior surface of the tempral lobe, the posterior ectosylvian area (Ep), and the second somatic area (SII) which receives projections from that area of the midbrain where the posterior division of the thalmic nuclei and the medial geniculate body border on one another (Rose and Woolsey, 1958). And in addition to the afferent and centrifugal fibres which are now well known, it has recently been emphasised by Magoun (1954) that there are collateral pathways to the classical auditory afferents which pass to the thalamic reticular system and thence by relays to the cortex.

As Nakao and Keolla have said,

> "The reticular formation not only draws collaterals from the ascending sensory paths throughout its course . . . . . but also feeds back into the sensory paths at several levels."
>
> (Nakao and Koella, 1956).

This and the other recent work which supports it is of very great importance for our purpose, for here we have two pathways, separate anatomically, by which auditory information can be carried to those parts of the brain which are concerned with perception. Can we find evidence that these different pathways are in fact concerned with different kinds of analysis of incoming stimulation?

There has recently been renewed interest in the extent to which animals are able to function without their auditory cortex, and in particular two papers, the first by Neff and Diamond, and the second by Rose and Woolsey, have appeared (1958) in the symposium on Biological and Biochemical Foundations of Behaviour.

The former considered the effects of cortical ablation on pitch discrimination, pattern discrimination, and auditory localisation. They found that after the excision of AI, AII, Ep, and SII the animals' ability to perform pitch discrimination was hardly impaired, and this agrees with other findings in this field. Auditory localisation was somewhat damaged, but subsidiary experiments suggested that this was due to defects in the animals' ability to concentrate rather than direct interference with the mechanisms responsible for auditory localisation. What was lost, however, was the ability to discriminate temporal patterns. This agrees with the work of, e.g., Sharpless (1954).

Now if the cortex is required only for the perception of patterns, but not for the processing of "raw data", (by which is meant relatively simple discriminations of pitch), and this latter can be done by lower centres in the brain, such as the medial geniculate body; then we have the possibility at least that one of these mechanisms could be blocked at some point between the lower and higher analytic

centres. For example it might be that out-put from the medial geniculate body to the main auditory cortex would be blocked, but the alternate route to the reticular formation would be left open. If some such system does in fact exist, (and it must be emphasised that we do not yet know enough to say that it is definitely at this level that the block occurs), then the selective blocking of "pattern analysis" with the maintenance of "raw data" analysis could occur in this way. Even if, as we shall see, the afferent impulses are probably not blocked below the level of the cortex, their arrival there would not be sufficient necessarily for the perception of pattern, for Samuels (1959), reviewing the data on reticular system functions, concluded,

> ". . . the arrival of specific sensory impulses in the cortex is not, in the absence of non-specific reticular activity a sufficient condition for the conscious perception of these stimuli."

and

> ". . . the classical afferent systems transmit the information which forms the specific content of consciousness, but do not per se mediate awareness . . . Rather it is the activity in the nonspecific Reticular System which provides the essential neurophysiological condition for the processes of perception, attention, and sensation."
>
> (Samuels, op.cit.)

Thus we see that by the "funneling off" (as it has been called), of data by collaterals into the reticular system after it has passed through a simple discrimination mechanism but before it reaches the pattern analysing mechanisms of the cortex, we could have just the sort of performance that we find in the selective dichotic shadowing situation - that fairly simple characteristics of the rejected message are noted, but the complex "pattern meaning" characteristics are not.

The above evidence suggests that the anatomical substratum of such a dual system may exist - at least in certain animals. But there is also other behavioural and neurphysiological evidence that indicates its existence. Sharpless (1954) has shown that it is possible to have reticular and behavioural adaptation to clicks in the cat without any change in the cortical potentials due to the click stimulation. Excision of AI, AII, Ep, and SII has no effect upon this adaptation, so that the reticular system must be adapting to impulses which reach it by a route which does not pass through the cortex. This is rather the reverse of the results which we have just been discussing: for here we might conclude that the response of the "raw data" part of the system has been lowered without affecting the activity of the pattern analysis mechanisms. Rose and Woolsey (1958) have reported that adaptation to pattern on the other hand does not occur without the cortex.

It seems safe to conclude from the above, that adaptation to patterns and to simple stimuli could involve two distinct mechanisms, either of which can be affected without altering the other, which was the conclusion which we were hoping to be able to reach. This conclusion is further strengthened by the work of Sharpless & Jasper (1956) who found that when a cat habituated to pure tones the cortical response actually increased, as the behavioural signs of responsiveness to the tones decreased.

These results are all, however, based on experimental lesions and work with implanted electrodes in animals - usually the cat. Is there any evidence of similar facts in the case of man?

Ziegler (1952) has reported a case of pure word deafness. This is a form of receptive Aphasia which is similar to Wernicke's aphasia, but differs from it in this important respect: that there is little or no change in the auditory threshold; simply the meaning of words auditorily presented is lost to the patient. If his threshold is measured using pure tones or white noise it differs very little from that of an ordinary person; but he is unable to apprehend words as words - they remain simply sounds for him; and similarly music is now heard as sound, not as a melody. As far as is known the lesion which gives rise to this syndrome is a parieto-temporal one, which does not immediately tie up with the studies of the excision of AI, AII, Ep, and SII, but does at least indicate that it is possible to knock out the "meaning" analysis system in man without impairing very much the "raw data" response system.

Samuels (op. cit.) has summarised these conclusions well, as follows:

> "1. At the level of the sensory receptors, the spinal cord, and in the specific sensory paths prior to the point at which they give off collaterals to the reticular formation, both the arousal and cue effects of stimuli may be controlled.
>
> 2. In the reticular formation itself, the arousal effects of stimuli may be enhanced or inhibited.
>
> 3. In the cortex the cue value of stimuli may be affected."

where by "cue value" she means what has been variously called "meaning", "pattern analysis", or "complex stimuli" above. Her use of "arousal effects" is not quite the same as the writer's use of "raw data" or "simple stimuli", but both refer to reactions which are much cruder in

terms of the level of analysis of the signals which is required. The use of various terms to describe the sort of stimuli in each class rather than one term for each is done advisedly, because of the difficulty of using a term such as "meaning" in a proper way when talking of animal which do not have verbal languages.

We may conclude that there is a certain amount of neurophysiological evidence for the existence of a dual system with differing degrees of sophistication of function, and whose parts have properties which can be independently varied in the auditory system.

2. Evidence for the levels of the nervous system at which the comparators lie

A. R_x: the mechanism for auditory localisation and the dichotic/binaural decision.

The most directly relevant information about this problem comes from the already-quoted paper by Neff and Diamond (1958). In their study on the effects of cortical ablation upon auditory discrimination they gave a preliminary report of some experiments by their co-workers Blau and Nauman, upon the effects of various lesions on auditory localisation in cats. They found that they could make very extensive cortical lesions on both sides, but that the ability to localise sounds remained. Callosal section, or section of the commisure of the inferior calliculus likewise had no effect upon the ability of the animals to localise sounds, but section of the trapezoid body had a very serious effect, virtually abolishing the ability to localise.

Now the best developed theory of the mechanism of auditory localisation is that due to Cherry (1957). The success of this theory in predicting the performance of human subjects is quite outstanding, and even if some features of behaviour are found which necessitate the

modification of this model it is almost certainly correct in the main outlines. It consists of a series of correlators and a detector. In the first place the input from each ear is auto-correlated, and the time average of the wave thus obtained is then fed to a cross correlator. Here the inputs from the two sides are correlated, and on the basis of the position along a correlation surface of the maximum value of the correlation function a decision is taken by the detector as to the localisation of the source of sound.

For the purposes of our present discussion, then, we want to find two parts of the nervous system: firstly, a unit on each side, probably fairly low down in the afferent pathway, which looks as though it might perform a running auto-correlation on signals passing through it, and secondly, some place in the nervous system at which the outputs from the two auto-correlators can meet. Moreover, this latter must be so placed that its function can be interrupted by trapezoid body section.

The calculation of the running auto-correlation function, according to the equations suggested by Cherry, requires that the value of the wave at any given moment be compared with all other values which it has taken over a short period immediately before that moment, and during a short interval. In general what we should look for is a network in which the signals arriving at time t are represented and matched against parallel representations of recent signals, perhaps utilising a series of delay networks of differing time constants. It is not worth going into the question in more detail at present, for the neurological evidence is rather meagre; but there is one structure low

down in the auditory pathway which looks as though it may have the requisite structure, and that is the cochlear nucleus. Galambos (1954) describes the cochlear nucleus complex as being more complicated even than the retina, and in particular remarks that all afferents from the cochlea enter the medulla, bifurcate, and then make synapses with at least each of 13 distinct subdivisions of the nucleus. In each of these 13 divisions the basilar membrane is represented, the low tones along the inferolateral margin of the complex, the high tones along the dorso-medial margin. And apart from this orderly array of repeated mapping of the cochlea there is a diffuse network of fibre endings and a well marked system of short-axon cells connecting each one of the 13 subdivisions to the others. Without wishing to insist on this point, it is clear that the cochlear nucleus is of sufficient complexity to perform the sort of function that is required, and may eventually turn out to be the auto-correlator required on Cherry's model. Alanson and Whitfield (1953) have recently begun to investigate the input-output relationships of this nucleus with implanted electrodes, and this sort of work may throw more light on the problem in the near future.

But with regard to the position of the cross-correlator it is rather more difficult even to make a tentative suggestion. What is required is a place where the afferent impulses from the two ears meet, and which lies in such a position that section of the trapezoid body prevents this meeting. It might be a single central structure, into which the afferents run, or a double structure represented on both sides of the brain, so that the operations on the input are duplicated.

It seems unlikely that the cross-correlation is being done at the level of the inferior colliculus. Even if the trapezoid body is

sectioned, afferents from both ears will still run into both sides of the inferior colliculus, along the pathways which relay in the olivary nuclei. At the lateral leminisci only fibres of contralateral origin form synapses, so that the comparison could not be done. The nucleus of the trapezoid body receives only contralateral fibres, so that the same objection applies. The only structures which receive afferents from both ears, and which are so placed that trapezoidal section would interfere with this input are in fact the olivary nuclei.

Each olive receives fibres from both ipsilateral and contralateral cochleas, via fibres which arise in the ventral cochlear nucleus synapse of the auditory nerve. Galambos (1954) reports that the olivary relays are the main relays of the cochlear cortical pathways at this level, and that some 90 - 95% of fibres leaving it are destined to be more or less equally distributed to the two lateral lemnisci. Moreover other fibres run from it to make connexions subserving reflexes with the motor nuclei of the eye muscles, middle ear muscles, and muscles of the face, neck, and body - which is very much what one would expect of a centre concerned with the problem of auditory localisation.

While tentatively concluding therefore, that the R_x correlation may be done in the olives, it is worth while noting one peculiarity of the auditory pathways which may hide something of great significance which we do not as yet realise. If we regard the relay points along the afferent pathway, there seems to be a curious sort of "leapfrogging" going on. The fibres leaving the dorsal cochlear nucleus do not relay in the trapezoid body or olives, but do relay in the lateral lemniscus. Those fibres which rely in the olives do not

relay in the lateral lemniscus, but do relay at the inferior colliculus, while those which relay at the lateral lemnisucs do not relay at the colliculus. Presumably what we see here is in some way related to differential function, or some sort of interaction in which timing plays a part, so that the above suggestions about the site of the R_x mechanism may turn out to be wrong when we know more about the cause of the "leapfrogging" of the auditory fibres.

B. R_p & R_s: the mechanisms for utilising context in listening to speech.

The requirements for these mechanisms are as follows: we must look for a neuronal circuit in which afferent impulses pass to the cortex, to that part of the brain where they may come into contact with the long term memory store, then to descending pathways, and hence back into contact with the afferent system again.

It must be admitted that the evidence for identifying this circuit is extremely scanty. From the work of Penfield and his co-workers (see Penfield and Roberts, 1959) it would seem that we must look for a pathway bringing afferent stimulation into contact with the parieto-temporal region, if the long-term verbal storage system is to be involved, since there is now a considerable amount of evidence to suggest that it is this area which is particularly concerned with verbal memories. And it would not be too rash a suggestion, perhaps, to say that the point at which the feedback path comes into interaction with the afferent inflow is connected to the reticular system of the brainstem, since there are now a large number of studies indicating that that structure plays a central part in integration and interaction. So we must now examine the auditory neurology for connexions periphery - cortex -

temporal lobe - reticular formation - afferent pathway.

The classical pathways by which the afferent auditory impulses are carried to the auditory cortex are now well known, and are more or less as shown in Figure (XVII). There do not seem to be extensive connexions between the auditory cortex and the reticular system. As Jasper (1958 has said,

> "The fact that the thalamic reticular system seems to possess a certain degree of topographical organisation relative to its cortical projections may provide a neurophysiological basis for the direction of attention. It would be necessary, however, for information elaborated in the cortex to be available to the reticular system if the system is to function in this capacity. It now seems that many corticofugal projections do exist, but we have not found them to be particularly strong from sensory receiving areas, especially for the visual system. The most important corticofugal projections seems to arise from areas which are not primarily sensory in function: frontal, cingulate, temporal, parietal, and area 19 in the occipital lobe. It seems likely that these elaborative areas may form an intermediary system between the primary cortex and projections to the centrencephalic system."

And Samuels (1959) has also drawn attention to the strength of the temporal-reticular projection. French, Hernandez-Peon, and Livingston (1955) have said,

> ". . . potentials in the brain stem concerned with arousal mechanisms may be induced by stimulation of . . . the tip of the temporal lobe and the superior temporal gyrus . . ."

among others, when discussing cortico-thalamic connexions in the monkey. It is also well known that there are connexions from the auditory cortex to the parieto-temporal region, so that there seem indeed to be pathways which could (although of course may not) be concerned in such a circuit as is here being postulated.

With regard to the feedback from the reticular formation to the afferent pathways, it is now well accepted that there are reticular neurones which end on all the major synapses of the classical afferent pathways, and as Nakao and Koella have said in a quotation to which we have referred before,

> "The reticular formation not only draws collaterals from the ascending sensory paths throughout its course . . . but also feeds back into the sensory paths at several levels."

In addition, Rosensweig and others, in a series of electrophysiological studies have shown that at each of the relays in the ascending pathways of the auditory system, medial geniculate, lateral lemniscus, and inferior colliculus, there are pathways by which there is interaction between the two sides of the auditory system, so that if indeed the hypothesis suggested is correct, the connexions available for the interactions present almost an "embarass de richesse". None of the studies done on this part of the auditory system have been performed in the context of ideas such as are here being presented, and until we are more certain of exactly what questions to ask, the neurological data must remain sparse. In the final chapter of the thesis some suggestions as to possible experiments will be offered.

3. The problem of pattern analysis below the level of awareness

By recent radition this question is very contentious, since it is usually discussed in the context of what is variously called "subception", "subliminal perception", and so on. The difficulties of interpreting such studies are well known, and need no elaboration here: and moreover until the facts are clearer in the behavioural field, there seems little to be gained from speculating on the neurology of the phenomenon. For the present, we shall be concerned with evidence

that the brain can perform pattern analysis when the subject is definitely not conscious of the stimulus, and that without the subject being conscious the brain is able to respond selectively to certain patterns of stimulation. If we can establish in what part of the brain such analysis is done, then we may well speculate as to the identity of this region with that responsible for giving selective responses of the type called the "identification paradox" in Chapter IV.

One way to show that the brain is capable of pattern recognition without the conscious awareness of the subject would be to show it occurring during sleep. Perhaps the simplest example is the role of external stimuli in the production of dreams. Freud (1915) has discussed in some detail the way in which the ringing of a bell, for example, can give rise to a dream in which some sound which is similar to the bell plays a very important role. But often the bell itself does not intrude in the dream, at least not in the manifest content. The alarm clock may become a church bell, the knocking on the door become a gun firing; and a richly elaborated dream sequence may then follow until the dreamer awakes a few seconds later. But although the bell or knocking may not be heard as such, the way in which their sounds are used in the development of the dream suggests that they have been analysed correctly by the brain while the subject is asleep.

Recently this question has been put on a firmer experimental basis with the work of Oswald, Taylor, and Treisman (1960). They took 36-hour-sleep-deprived subjects and played tape recordings of

various kinds to them while they slept. The subjects went to sleep with EEG recording electrodes attached to their heads, and a continuous record of the brain responses was made during sleep. The tape recordings consisted of lists of names, including the subjects' own, and various kinds of tonal patterns (for example three short pips in succession rising in pitch, with here and there one train which fell in pitch). They found that subjects awoke more readily to their own names than to the names of other people; that they gave more K- complexes without awaking (the K-complex being generally accepted as a measure of arousal) to their own than to other people's names; and that GSR responses were made more frequently to their own names even when the subject did not awake. In the case of one subject GSR's were obtained also to the name of a recently acquired girl friend without the subject awaking. Similarly, whereas the subjects adapted fairly quickly to the trains of pips, when the reversed ones came they tended to give K-complexes. The experiments were controlled for possible artefacts such as differences in the loudness of spoken names, rate of onset of stimulus, etc., and the whole study is extremely elegant. From it we may certainly conclude that quite complex pattern analysis can be performed by the brain without the subject being consciously aware of the nature, or even the occurrence, of the stimuli.

This experiment throws considerable light on the level at which the blocking of the afferent messages is occurring. There is now a wide measure of agreement between the many studies on animals about the necessity of the auditory cortex (AI, AII, Ep, and SII), if patterns are to be discriminated. We have already seen that both Sharpless and Jasper (1956), and Neff and Diamond (1958) have found cats unable to

discriminate tonal patterns in the absence of their auditory cortices, although able to distinquish simple differences of pitch. So if we can equate the studies of Oswald et al. (op. cit.) with the experiment on affective stimuli reported in Chapter IV above, we may conclude as follows.

Whatever form the "block" may take, whether it is a switch or attentuator, and whichever of the models mentioned may best describe its function, the afferent impulses carrying information about the content of the rejected message (or the signals in sleep) probably reach the auditory cortex along the classical afferent pathways, and the "block" is to be found somewhere in the pathways leaving the cortex for other parts of the cerebrum. This would be in accord with the statements of Samuels (1959):

> "The classical afferent systems transmit the information which forms the specific content of consciousness, but do not per se mediate awareness (Gellhorn, 1954). Rather it is the activity in the nonspecific reticular system which provides the essential neurophysiological condition for the processes of perception, attention, and sensation."

and,

> ". . . the arrival of specific sensory impulses in the cortex is not, in the absence of non-specific reticular activity a sufficient condition for the conscious perception of these stimuli."

The successful recording of specific GSR responses by Oswald et al. further supports this idea, when taken with the (probably) positive result of the conditioning experiment reported in Chapter IV. Speaking of the human GSR response in conditioning, Duret-Cosyns and Curet (1956) have said:

"Although Fauville, and Schwartz have shown the existence of segmental GSR in the decerebrate animal, it seems that in man the integrity of the cortex is essential. Doig, Wolf, and Wolff working with a human suffering from a damaged skull, pathologically decerebrate, were unable to show any GSR response.

"We have studied 5 cases of confused and subcomatose patients reacting violently to cutaneous stimulation, even when it is slight, by shouting, and by withdrawal of limbs, and have been unable by any means, including auditory, visual, tactile, electric, etc., to produce the slightest sign of GSR activity."

(Translation by the present writer)

In an earlier study, Oswald (1959) had also managed to condition sleeping subjects to electric shocks of considerable ferocity (400 volts). This too would tie up with the conditioning experiment reported in Chapter IV, and with some further remarks of Samuels:

"However, the functional value of a more differentiated arousal system capable of localised control of the specific projection areas is unquestionable. Through selective facilitation or inhibition of various sensory inputs in the cortex, such an anatomical arrangement would provide discriminative control over the elaboration of the specific sensory potentials at a cortical level and thus permit greater flexibility and more finely graded regulation of processes involving selective awareness, perception, and memory than is possible through peripheral sensory control."

And we may finally quote Jasper (1958):

"The fact that the thalamic reticular system seems to possess a certain degree of topographical organisation relative to its cortical projections may provide a neurophysiological basis for the direction of attention. It would be necessary, however, for information elaborated in the cortex to be available to the reticular system if the system is to function in this capacity. It now seems that many corticofugal projections do exist, but we have not found them to be particularly strong from sensory receiving areas, especially for the visual system. The most important corticofugal projections seem to arise from areas which are not primarily sensory in function: frontal, cingulate, temporal, parietal, and area 19 in the occipital lobe. It seems likely that these elaborative areas may form an intermediary system between the primary cortex and projection to the centrencephalic system."

This is most likely to be true in man, for as has been pointed out already, in man the development of a predominately unilateral representation of speech and language in the brain must lead to some further processing of incoming signals beyond that found in lower animals at the level of the classical auditory cortex. But whatever the details of this may be - and it must be emphasised that for all the work done by the neurophysiologists there is very little that is known about the details of these processes - it seems safe to conclude that point at which the "rejected" information in selective listening or sleep is prevented from reaching the level of conscious perception by the subject lies between the auditory cortex and the reticular system.

4. The mechanisms of switching of attention in selective listening.

It will be recalled that in chapter III, when offering the general model for selective listening, it was held that the subject's performance in a particular experiment would be the outcome of the interplay of several interacting mechanisms. These were (a) the "bias" introduced by descending impulses from those parts of the brain mediating the subject's voluntary decision to listen to one ear and reject the others, (b) certain physical characteristics of the message itself, for example its intensity, (c) the effect of the type of message which was being listened to in terms of its signal structure - the effect of transitional probabilities between signals, and the contextual effect of past experience of language, which would tend to keep the subject shadowing a particular message, (d) the effect of the auditory localisation mechanism as to whether there were one binaural or two dichotic messages present, to which, as we have seen, we must add

certain "affective" effects of some signals, which may selectively be admitted to the perceptual mechanisms even though by and large the input along the channel through which they arrive is being blocked. Where do these various factors operate?

In view of the various quotations which we have considered there seems little doubt that the key to these selective processes in perception lies in the interplay of activity between impulses in the classical afferent pathways of the brain and impulses in the reticular formation. We have seen that Samuels concludes on the basis of the literature which she has reviewed that for a message to be perceived it is not sufficient for either the cortex or the reticular system to be activated singly, but that there must be simultaneous activity in both, so that the "cue value" of the cortical analytical system can be received by an "activated" centrencephalic system. If we ask where the "bias" is introduced in selective listening, the answer would seem to be that it originates in the frontal lobes. This is very much a guess, based solely on the agreement of many clinical studies in that the effect of frontal ablation is to reduce the ability of the patient to sustain his voluntary activity in general. Whatever view one takes of the general concept of "voluntary acts", it would seem that the frontal lobes may be involved in their execution. Moreover there are known to be pathways from the frontal area to the reticular formation, and thus the sort of "biassing" of the auditory system which we are discussing could be brought about.

There are also descending pathways present at every level of the auditory tract, from the cortex down to the cochlea, as were

indicated in Figure (XVII), as well as pathways by which lateral interaction between the two pathways can occur at every synaptic level. The anatomical evidence is reviewed in Galambos (1954). Some recent work of Hernandez-Peon and his co-workers (1958) at first sight suggests that there might be blockade of the afferent inflow at a very low level in the auditory path. He found, using chronically implanted electrodes in unanaesthetised cats, that when the cat looked at mice in a bowl, or sniffed sardine odour, that the potentials in response to clicks were much reduced in size if not abolished at the level of the cochlear nucleus of the trapezoid body. And Galambos (1955) has shown that by stimulating the olivo-cochlear bundle of centrifugal fibres in the trapezoid body it is possible to alter the response of the cochlea itself. But in view of the evidence discussed in the last section concerning the GSR conditioning response and the selective responses of the subjects in sleep, it seems well-nigh impossible that the blocking effect which Hernandez-Peon and Galambos have found can be concerned in situations where responses to complex stimuli are made.

As we saw in the last section, the necessity for the auditory cortex to be functional if pattern analysis is to be achieved means that we must look for the blocking mechanism - of whatever kind it is - somewhere after the auditory cortex. The quotation from Jaspers given above (p. 1958) supports the idea of an interaction between cortex and reticular system, and specifically mentions the existence of cortifugal reticular neurones. And Samuels has drawn attention to experimental evidence of such cortical-reticular interaction. She says,

> "Simultaneous convergence of a peripheral sensory impulse and a corticofugal potential upon a reticular unit led to facilitation of the reticular response . . ."

and she goes on to discuss these interaction effects in terms of habituation and similar phenomena. Further, she says,

> ". . . the primary evoked potentials elicited by excitation of a peripheral nerve were reduced or blocked in the cortex by intense reticular arousal (Gauthier et al. 1956) . . . . hypothalamic stimulation interacted with the specific sensory impulse to give both an intensification of the amplitude of the cortical evoked response and an increase in the area from which it was recorded. (Gellhorn et al., 1954). This interaction of hypothalamic stimulation with a specific sensory stimulus occurred chiefly within the corresponding projection area (i.e. hypothalamic interaction with an acoustic stimulus affected the auditory projection area), but, to a lesser extent, it increased the response of another region, (i.e. the visual area), to stimulation."

It is clear that this sort of interaction is very much what would be expected of a system of the sort which we are considering.

The discovery of the existence of collaterals given off by the ascending afferent pathways to all levels of the reticular formation, with reticulo-fugal paths running in the opposite direction to end on the synaptic junctions of the sensory paths (Magoun, 1954), shows that there are ample pathways for the reticular formation to influence the auditory system in the way required. Samuels says,

> ". . . the functional value of a more differentiated arousal system capable of localised control of the specific projection areas is unquestionable. Through selective facilitation or inhibition of various sensory inputs in the cortex, such an anatomical arrangement would provide discriminative control over the elaboration of the specific sensory potentials at a cortical level and thus permit greater flexibility and a more finely graded regulation of processes involving selective awareness, perception, and memory than is possible through peripheral sensory control alone."

Moreover, the timing of neurological events in this region appears very much what one would expect if indeed the selective mechanisms are located here. The same author says,

> "The latency of the specific evoked potential in the sensorimotor cortex following stimulation of the sciatic nerve was 9 - 10 msecs. In the midbrain reticular formation, the conduction times ranged from 13 - 23 msecs. (French et al., 1953). This difference of 4 - 14 msecs. when compared to the 6 - 12 msecs. latencies of potentials from cortical areas to the reticular formation (French and Hernandez-Peon, 1955) suggests that there is time for a stimulus to reach the cortex via the specific paths and then relay down to the reticular formation in time to affect its own arousal properties."

As regards the effect of the auditory localisation mechanisms on the selective mechanisms, it was suggested above that the information about which ear, or rather which channel, a signal had arrived along might be sent up to the perceptual mechanisms from the R_x correlator to supplement the information present in the afferent impulse itself. Galambos (1954) reported that there was a pathway from the trapezoid body the reticular formation, and if the speculation that R_x is located in the olivary nuclei is correct, this might be the way in which the localisation information is brought into the area of interaction.

The overall picture, then, would appear to be somewhat like this. The afferent pathway splits at some point below the auditory cortex, sending one set of impulses on to the cortex, and another (those concerned with the comparatively simple discriminations) only to some lower centre. From these analysis centres both pathways send fibres to the centrencephalic perceptual system. The "block" which is seen in selective dichotic shadowing, whereby the meaning of the rejected message goes unperceived, lies between the cortex and the reticular system, or may at least be so described, although if it is simply a matter of altered thresholds of the pattern analyser, rather

than a block at some synapse, it might be more accurate to describe it in some other terms: the change in thresholds might actually occur in the cortical pattern analysers. The decision about this must await further work on the nature of the perceptual mechanisms involved in language. The block can also be affected by stimuli from other modalities, (see the experiment by Gellhorn (1954) quoted by Samuels, above). But it is unlikely that the peripheral blocking mechanisms found by Hernandez-Peon and Galambos are concerned in this response. They may be part of a system, rather, concerned with switching the attention from one modality to another.

To conclude with a final quotation from the exceptionally good review by Samuels,

> "1. At the level of the sensory receptors, the spinal cord, and in the specific sensory paths prior to the point at which they give off collaterals to the reticular formation, both the arousal and cue effects of stimuli may be controlled.
>
> "2. In the reticular formation itself, the arousal effects of stimuli may be enhanced or inhibited.
>
> "3. In the cortex the cue value of stimuli may be affected."

which, it must be admitted, summarises about all that is known of the neurophysiology of selective listening which is not highly speculative. More definite statements must wait upon a considerable progress in neurophysiology, although present workers may be comforted with being at least slightly better off than the author whose quotation heads this chapter, at any rate with regard to the mechanism of attention.

CHAPTER VIII

Conclusions and Prospects

"Base Camp at last".
(S. Clark, The Puma's Claw).

This thesis is a progress report, not the definitive account of the field with which it is concerned.

Despite how striking is the phenomenon which was reported by Cherry in 1953, that in selective dichotic shadowing of speech the subject remains completely ignorant of the content though not of the general characteristics of the rejected message, it seems that no one has previously followed up this research. As far as it is possible to discover, only the present writer and Taylor (1958, 1959, 1960) have continued Cherry's original work. How much of an advance has been achieved ?

It seems fair to say that we can now see at least something of the range of the problems which must be solved if an account of the phenomena is to be given. Enough data has been collected to provide a model of considerable complexity, although not as yet one which has a very rigorous form. It is not proposed to give a full account of the model again here, since the accounts of Chapters III and IV can readily be combined. But perhaps a very brief summary would be useful.

It is assumed that by the subject's voluntary decision he may block the input pathways from one ear or other to the speech analysing mechanisms of the brain if two messages are presented

dichotically to him. Even if he does this, however, he cannot block the pathways to comparatively "low level" analysis mechanisms for the rejected message. By comparing the structure of the messages the brain makes decisions as to whether there are one or two messages present, and this mechanism can override the voluntary decisions if the messages are sufficiently similar. The brain also makes use of the learnt transitional probabilities between the signals of a language to predict what later parts of the message will be on the basis of the earlier parts, and utilises these predictions to make sure that the correct message is selected. Certain "important" stimuli such as a person's own name can override most settings of the mechanism and will then "capture" the subject's attention.

Now during the discussion in Chapters III and IV it was said that the writer doubted whether the model suggested would prove to be an adequate description of the mechanisms involved; and it might reasonably be asked why he then bothers to put it forward at all. On the whole it seems true to say that no model, strictly speaking, can be put forward as the last word about a subject. Even in physics it has come to be realised that the most perfect model available is always likely to be displaced by subsequent research, or at least shown to be of limited application, and satisfactory over a limited range of conditions.

The present writer regards the function of a model as at least threefold; to summarise existing data, to allow an overall view of the field with which it is concerned (a conceptual foothold

as it were on the crag of the problem at issue), and to suggest further experiments. In the present thesis, the model has been presented in two forms, a flow-diagram and a formal (though loose) set of propositions. Of these it is the latter which is important, the flow-diagram being merely a kind of "aide-memoire". Ideally the set of propositions should be of such a form that each can be experimentally tested in a single experiment, being so unambiguously worded that the attack on the truth of the proposition can be simple and direct. The propositions need not be quantitative, but must be precise. Examples of formal, non-quantitative models of this kind have recently been given by Deutsch (1955), and Broadbent (1958). In theory these models can be tested by taking each postulate in turn and submitting it to exprimental attack; or if some of the postulates are hierarchically arranged, by submitting those to attack which are logically more basic to the theory.

In its present form the writer's model for selective listening does not contain many propositions which are sufficiently precisely stated to make it an adequate model of this kind. For example, it was suggested that the reason why subjects follow a message for a few words on the "wrong" ear in a shadowing situation, when the two messages are suddenly exchanged, is because the mechanisms are predicting on the basis of transitional probabilities what those words should be. But in order to make the model rigorous, something should be said about the relation between this effect and that due to the "biassing" of the switching mechanism by the higher centres. For example, one of the propositions might read,

> " Assuming that the biassing effect is held constant, the duration of time for which the subject will switch is inversely proportional to the information content of the message. "

But at present it does not seem worthwhile to try to make the model over-rigorous, for there are still too many factual questions unanswered: we do not know, for example, whether the duration for which the subject switches in the above situation is more properly described in terms of a time span or a span of number-of-words.

But while it is not practical to put forward a concise and well-developed system now, it is certainly worth pausing to survey and collate the results. The present model does at least provide a conceptual foothold, as it was called above, and provides a summary of data, which Taylor's work augments. And certainly a large number of experiments are suggested. The model could be developed along two lines - qualitative and quantitative. The first would involve tidying up the loose ends of the model so that the propositions could be more formally stated and subsequently attacked. Quantitatively there are several points at which it would be suitable to develop specific equations whose predictions could be tested. For example, much has been made of the idea of correlation of incoming signals in the model, and it would be possible to suggest, as Cherry has done for auditory localisation, the equation which specifies the particular correlation function which is being used.

One the subject of future expriments, the following experiments are fairly obvious.

1. It is clear that since the model makes use of the

concepts of information theory the rate at which signals enter the system is of great importance in predicting what is going to happen in any given situation. For example, consider the "lead-lag" experiment described in Chapter III. Is the difference between the two situations one in which the number of words is crucial, (that is, the capacity of the memory store is critical for deciding at what point the two messages will be recognised as the same), or is it a genuine effect of rate, (if the two messages are far enough apart in time the trace of the first fades) ? The importance of timing has been indicated by Taylor (personal communication) in an experiment on the shadowing of statistical approximations to English. She found that by slowing down the speech rate the rise in errors at lower orders of approximation could be offset, and that the alteration of rate was such as would be predicted according to information theory considerations. There are several such points in the model where time or the number of signals may be the limiting factor and we do not know which. This needs elucidating.

2. Next, and related to the last, the work of Taylor should be continued, and a study made of the effects of languages which have different probability structures. This will probably mean the construction of further samples of statistical approxiamtions to English and other languages, and it would be nice to have a measure of the absolute amount of information in such samples, if it were possible to obtain this. There are certain suggestions in the literature which might lead at least to an approximate estimate of this figure. Since in the model such an emphasis is

laid on the role of the probability structure of the messages in determinging the subject's responses, it is of great importance that attempts should be made artificially to tamper with the probability structure of the stimuli used.

3. The previous paragraph is concerned with the R_p and R_s units of the model, but there are also unknown properties of the R_s mechanism. The effect of very short time intervals between messages, such as are found in the auditory localisation experiments, are fairly well known now, but there is a second range of times which have not been investigated, those where the brain makes the decision as to whether there is a single binaural message or two dichotic messages. By the time that two messages are separated in time by about 0.66 milliseconds at the two ears, if the content of each message is the same, it will be heard as a single message localised opposite one ear. If the time difference is now increased to about 15 milliseconds, the message suddenly breaks into two, one at each ear, saying the same thing. This range of timing deserves further investigation to discover the variables involved in the decision.

4. The question of switching time remains unresolved. It was suggested that a search for shorter signals should be made, and by using them an experiment designed to see whether the duration of the signals has a marked effect on the estimate of "perception time + switching time". Secondly, a search should be made for an experimental design which ensures switching.

5. Finally, as far as suggestions for experiments using behavioural techniques are concerned - there is the question raised

by the examination of the varied ways in which the concept of attention appears in the literature. Can we show that there are several distinct kinds of behaviour, which may be assumed to be carried out by different mechanisms, and to vary independently, all of which are called "attention" in the literature ?

All the above programmes of research stem from unanswered problems in different areas of the field of which the present thesis provides a review; but there are also several lines which seem profitable from a neurophysiological standpoint.

The anatomy of the auditory pathways is quite well known. Indeed, by comparison with, say, the visual system, there is an extraordinary wealth of detailed information about the afferent and efferent pathways, the pathways of lateral interaction, and the places at which the three come into relation with one another. It seems a particularly promising field in which to set about the duplication of the behavioural results using a combination of conditioning and direct recording from the brains of animals. The development of techniques for using chronically implanted electrodes in cats, by workers such as Hernandez-Peon, has given us a very powerful research technique. It does not seem out of the question to make stimuli "artificially important" for animals, by shock and reward, much as was done with shock on human subjects in the GSR experiment described in Chapter IV. If so, it might be possible, by using several electrodes simultaneously implanted in the auditory pathway at various points, to pick up direct evidence of "switching" between ears.

Further, by carefully analysing the input/output relations

of the various relays in the auditory pathway, it should be possible to discover what the code is which the nervous system uses to transmit, say, the localisation information, and to track down the sites of the R_s, R_p, and R_x units (if they exist) by direct recording techniques.

Finally, not merely should it be possible to find the levels at which the block for pattern analysing lies, but the actual interplay of afferent and efferent impulses should be observable, by using the technique of several chronically implanted electrodes and a careful examination of the relative timing of ascending and descending impulses.

The position at the moment is one which is almost intoxicating in the riches which are offered to research. The present work may claim at least to have established a Base Camp, and for the first time the full difficulties of the problem come into view. Whatever the quality of the route so far traversed, there is no doubt that the ascent from here on holds promise of interest, excitement, and no little difficulty - but also of a most satisfying reward when the ascent is completed.

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